

Restoring the Great Lakes' Coastal Future

Technical Guidance for the Design and Implementation of Climate-Smart Restoration Projects

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Sharply Done





U.S. Geological Survey

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Executive Summary

The Great Lakes region is home to 20 percent of the world's freshwater reserves, a rich array of species and habitats, and tens of millions of people. One of the most significant challenges to the well-being of the region is climate change. We are already feeling the effects of climate change, and those effects will only intensify in the future. As a result the past alone is no longer a sufficient guide for conservation decisions. To effectively protect, manage, and restore freshwater coastal ecosystems in the Great Lakes we must integrate the reality of current and future climatic changes into our work. Making our projects "climate-smart" in this way will enhance their value and durability over the long term.

The purpose of this *Restoring the Great Lakes' Coastal Future* is to provide an initial suite of tools and methods to assist in the planning and implementation of climate-smart restoration by the National Oceanic and Atmospheric Administration (NOAA) and its partners and grantees. The guidance is intended to be a living document that evolves in response to workshops, trainings, on-the-ground projects, and other stakeholder input. Some ways that habitat restoration efforts funded under NOAA and partner programs in the Great Lakes region could be vulnerable to climate change impacts include:

- Changes in water temperatures and flow regimes may result in reduced use by target species or degradation of restored in-stream habitats.



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Making our projects "climate-smart" will enhance their value and durability over the long term.

- Warmer water may also facilitate the establishment of southern fish species such as smallmouth bass in the Great Lakes or the contraction northward of cold-water dependent species.
- Climate-related changes such as increasing temperatures, changing lake levels, reduced ice cover, and altered runoff patterns and lake chemistry will interact with a range of existing stressors, including increased input and toxicity of contaminants in freshwater systems.

This guide presents a project-based approach to adjusting restoration activities to address the realities of climate change. The steps are as follows:



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1. Identify Restoration Goals and Targets (e.g., restoring critical habitat for a particular endangered species or setting maximum allowable pollutant levels).

2. Identify Restoration Project Approaches (e.g., dam removal, revegetation, or recreating channels).

3. Assess Vulnerability of Targets/ Project Approaches to Change (e.g., the influence of temperature on species' health and reproduction or the toxicity of pollutants).

4. Identify Climate-Smart Management Options. (e.g., restore critical habitat in both current and possible future ranges of target species).

5. Select and Implement Management Options.

6. Monitor, Review, Revise.

Throughout this guidance, case examples illustrate how to apply this climate-smart restoration framework to the actual practice of restoration. These examples, including the restoration of whitefish spawning habitat and sea lamprey control, are presented in tabular format for easy reference. Tables review vulnerability of project goals, targets, and approaches to climate change, and present options for reducing that vulnerability on a number of levels. The body of this guidance is designed to provide an overall framework; more detailed information on conducting a vulnerability assessment and additional resources on restoration, climate change adaptation and the Great Lakes region are provided in appendices.

I. Introduction

Climate change has become the defining conservation issue of this century. Given current trends, the environment in which the planet's living resources – humans, plants, and animals alike – will exist in the future will be vastly different from the one we have experienced over the past several centuries, during which our conservation traditions evolved. In the United States, we are already seeing a plethora of changes, from higher average air and water temperatures and greater extremes in precipitation events to accelerating sea-level rise and an increase in the intensity of tropical storms.¹ Furthermore, these and other physical changes associated with climate change are having a significant biological impact across a broad range of natural systems.^{2,3,4}

Scientists and managers are examining how to balance near-term restoration goals for species and habitats with achieving ecologically functional, self-sustaining systems that can persist under likely future conditions.⁵ Managers can no longer assume that historical averages or trends will remain unchanged when setting their conservation and restoration goals, and must instead anticipate an increasingly variable and uncertain climate.⁶ Given this new reality, state and federal agencies, non-governmental organizations, and others concerned with conservation are challenged with designing and implementing projects that will maximize the effectiveness of restoration investments under both current and expected future climate conditions (i.e., projects that are climate-smart).



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The National Oceanic and Atmospheric Administration (NOAA), which is dedicated to the management and protection of the nation's treasured coastal and marine systems, is striving to safeguard its coastal investments in light of climate change and use those investments to enhance ecosystem resilience.⁷ This Technical Guidance provides information to assist in the planning and implementation of climate-smart restoration by NOAA and its partners and grantees, beginning with efforts in the Great Lakes region. The guidance is intended to be an ongoing work-in-progress, informed by workshops, trainings, on-the-ground projects, and other stakeholder-driven efforts.

II. Coastal Restoration in the Great Lakes

Setting the Stage

As the single largest source of surface freshwater in the world, North America's Great Lakes are a vital ecological and economic resource. More than 33 million U.S. and Canadian citizens call the coastal towns and cities of the Great Lakes Basin home. In addition, its scenic lake shores, unique wildlife, and diverse recreational opportunities draw millions of tourists to the region annually.

Unfortunately, growth in urban development, agriculture, industry, and tourism has brought enormous conservation challenges to the Great Lakes, even before the threat of climate change. Evidence of continuing problems has sparked concerns that the region's ecological systems may be nearing a tipping point of irreversible changes.⁸ A legacy of toxic pollution and contamination from substances such as mercury and PCBs threaten the health of people and wildlife

alike; populations of important native fish species have seen major declines due to overfishing and invasive species such as sea lampreys, zebra mussels, and common reed (*Phragmites*); the recurrence of anoxia/hypoxia and harmful algal blooms continues to plague coastal waters; and dredging activities and infrastructure development for water diversions, transportation, and other uses have damaged and fragmented habitats for fish and wildlife. Continued human population growth and increasing demands for freshwater are placing additional strain on Great Lakes resources.

Recognition that these and other serious problems must be addressed has prompted extensive restoration efforts in the Great Lakes region, across multiple scales – from local, community-based projects to major bi-national initiatives. Today, much of the Great Lakes restoration agenda follows from the Great Lakes Regional Collaboration (GLRC) Strategy, which was developed by a team of more than 1,500 people representing federal, state, local, and tribal governments; non-governmental organizations; and private citizens. Building on the GLRC Strategy, President Barack Obama and the U.S. Environmental Protection Agency (EPA) Administrator Lisa Jackson, in collaboration with 15 other federal agencies, have made restoring the Great Lakes a national priority. In February 2009, the President proposed \$475 million



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for a Great Lakes Restoration Initiative (GLRI), which is focused on five key challenges identified as the most significant environmental problems in the Great Lakes (other than water infrastructure):⁹

1. Cleaning up toxic substances and Areas of Concern (AOCs). *
2. Preventing or removing invasive species.
3. Improving nearshore health and reducing/preventing nonpoint source pollution.
4. Restoring and protecting habitat and wildlife.
5. Promoting and facilitating accountability, education, monitoring, evaluation, communication, and partnerships.

Notably, the GLRI defines a successfully restored system as one in which potential threats or future damage have been eliminated or reduced as much as possible, and the restored system is able to withstand future threats. This approach does not necessarily mean the system has been changed back to pre-European settlement conditions, but it does acknowledge that “a restored ecosystem does attempt to emulate those conditions

to the extent possible under present-day chemical, physical and biological conditions.”¹⁰

NOAA supports the GLRI through its Great Lakes Habitat Restoration Program, which plans, implements, and funds coastal habitat restoration projects throughout the region. NOAA's efforts focus largely on community-identified restoration priorities in AOCs, with the objective of delisting of fish and wildlife-related Beneficial Use Impairments (BUIs) . **

A critical question is, How can these and other restoration efforts best be accomplished in light of the significant impacts the region is already facing, and will likely continue to experience, due to changing climatic conditions? Recent trends and projections include: ¹¹

- Increase in average annual air temperatures;
- Increase in average precipitation, especially in winter and spring;
- Increase in the intensity and frequency of heavy rainfall events (see Figure 1);
- Increased evaporation and drought conditions in summer;

* Areas of Concern (AOCs) are formally defined in the 1987 amendments to the Great Lakes Water Quality Agreement as areas “that fail to meet general or specific objectives of the Agreement,” with resulting beneficial use impairments (BUIs). Building on earlier work, the U.S. and Canadian governments (in cooperation with the states, provinces, and International Joint Commission) identified 43 AOCs, where a common cause of BUIs is high levels of toxic chemicals. Following remediation and restoration work, two Canadian AOCs and one U.S. AOC have been formally delisted. Information on U.S. Great Lakes AOCs and BUIs are available at: <http://www.epa.gov/glnpo/aoc>.

** A Beneficial Use Impairment (BUI) is a change in the chemical, physical, or biological integrity of the Great Lakes system sufficient to cause any of 14 use impairments such as restrictions to fish consumption, water consumption or recreational activities covered by Article IV of the Boundary Waters Treaty Agreement. Source: International Joint Commission.

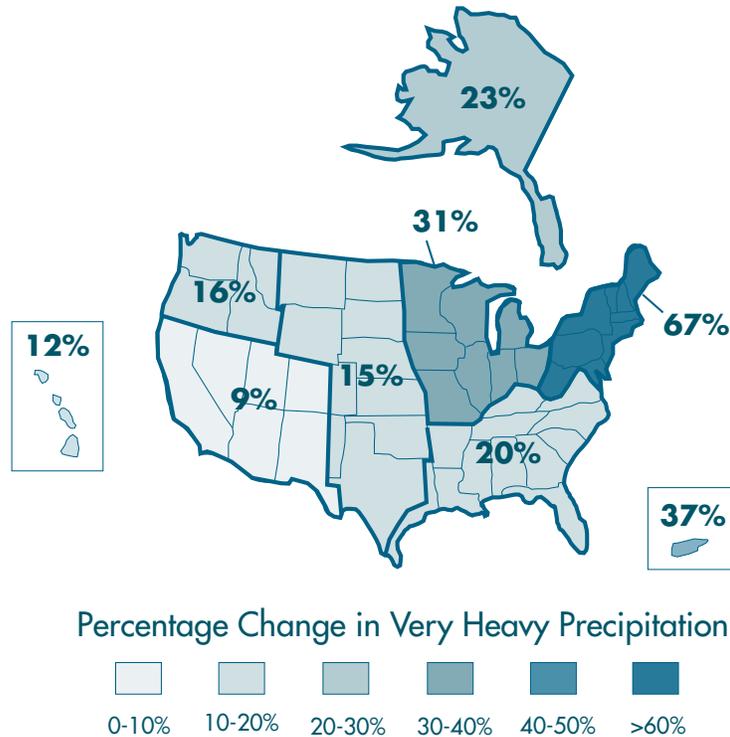


Figure 1. This map shows the percentage increases in very heavy precipitation (defined as the heaviest one percent of all events) from 1958 to 2007 for each region of the United States. There are clear trends toward more very heavy precipitation for the nation as a whole, and particularly in the Northeast and Midwest.^{14,15}

- Earlier last spring freeze and longer growing season;
- Decrease in ice and snow cover and duration, and earlier spring snowmelt;¹²
- Increase in Great Lakes water temperatures and increase in the duration of summer stratification;¹³ and
- Increase in the frequency and duration of low Great Lakes water level events and declining long-term average lake levels. (See Tables B and C in Appendix A for more detail).

This Technical Guidance presents a practical approach for restoration project planners to assess the vulnerability of their

projects to climate change and identify ways to avoid or minimize expected climate change impacts that would jeopardize the achievement of project objectives over the expected life of the project.¹⁶ Many of the most prevalent habitat restoration efforts funded under NOAA's programs in the Great Lakes region could be vulnerable to a wide variety of climate change impacts. For example:

- Changes in water temperatures and flow regimes may result in reduced target species utilization or degradation of restored in-stream habitats.¹⁷
- Coastal marsh restoration along the Great Lakes may be adversely affected by reductions in the frequency and duration of

freshwater inundation due to altered lake levels and streamflows.¹⁸

- Warming waters may facilitate the invasion and establishment of southern fish species such as smallmouth bass in the Great Lakes or the contraction northward of cold-water dependent species.¹⁹
- Climate change impacts such as changing temperatures, lake levels, ice cover, runoff patterns, and lake chemistry will interact with a range of issues related to contaminants, including changing the availability or toxicity of a number of contaminants and changing the pattern of input of toxic materials into freshwater systems.²⁰
- Toxicants can also increase species' sensitivity to various climate change impacts, for instance by decreasing thermal tolerance.²¹

In addition to considering how climate change might affect the ability of a restoration project to achieve existing restoration goals and objectives, it is also important that NOAA and others concerned with coastal conservation address climate change from a broader perspective – one that seeks to ensure that coastal systems across the landscape are as healthy and productive as possible in an era of climate change. Ultimately, this may entail reprioritizing current efforts as well as identifying new goals and objectives to reduce overall ecosystem vulnerability to climate change. While the toolbox of possible restoration activities is not inherently different for achieving these two goals, the process of strategy development is. In the climate change adaptation literature, these two approaches are

sometimes termed “bottom-up” and “top-down”.^{22,23} For this guidance, we describe them as “project-based” and “landscape-based” approaches, respectively.

- **A project-based approach** addresses the question: What are my conservation activities today, and how should I adjust them to address the realities of climate change?²⁴ The approach starts with specific conservation or management goals (e.g., protecting or restoring critical habitat for a particular endangered species, managing a particular wildlife refuge, or setting maximum allowable pollutant levels); identifying how climatic variables influence those conservation goals (e.g., the influence of temperature on species' health and reproduction or the toxicity of pollutants); determining plausible physical and ecological changes under a range of climate scenarios; and finally, identifying and evaluating options for reducing the vulnerability of one's restoration or conservation goals to those projected changes. A useful example of a project-based approach to developing a climate change adaptation strategy is the Alligator River Climate Change Adaptation Pilot Project initiated by The Nature Conservancy.²⁵ This project focuses specifically on promoting resilience while mitigating the effects of climate change on the Albemarle Peninsula of North Carolina, an important conservation area that includes the Alligator River National Wildlife Refuge and associated systems. The project focuses on the impacts of current and projected sea-level rise and includes tactics such as hydrologic restoration; land restoration, reforestation, and shoreline transition; oyster reef restoration; and measuring and monitoring project impacts on carbon sequestration.

• **A landscape-based approach**, on the other hand, addresses the broader question: What changes are projected to occur in my region of interest, and how can I respond? This approach starts with looking at one or more scenarios for shifts in climate (e.g., projections for sea-level rise/lake level changes, temperature changes, and/or extreme rainfall events); assessing what the future landscape might look like under those scenarios (e.g., what are some or all of the plausible ecological effects of the projected physical changes); and finally, setting specific conservation objectives and management priorities designed to address those projected future changes. The landscape-based adaptation planning approach is particularly useful for broad-scale efforts, such as those conducted at regional, state, or national levels for one or more sectors (e.g., agriculture, coastal communities, freshwater, human health, etc.). The Wisconsin Initiative on Climate Change Impacts (WICCI), which culminated in the recent release of *Wisconsin's Changing Climate: Impacts and Adaptation*, is a classic example of the landscape-based approach.²⁶ The WICCI is a collaborative effort among a diverse group of experts and stakeholders to: 1) assess and anticipate climate change impacts on Wisconsin's natural and built environments; 2) evaluate risks and vulnerabilities within the state's ecosystems, infrastructure, industries, agriculture, tourism, and other human and natural systems; and 3) recommend practical adaptation strategies and solutions that businesses, farmers, public health officials, municipalities,



National Park Service

resource managers, and other stakeholders can implement. The project-based and landscape-based approaches to climate change adaptation planning are not mutually exclusive. For example, some of the specific recommendations under the WICCI support a project-based approach of developing climate-smart restoration projects.²⁷

This guidance focuses primarily on the project-based approach to assist NOAA and others in minimizing the adverse impacts of climate change on particular restoration

projects with defined goals. Ultimately, a more landscape-based approach will be useful for developing or revising broader coastal restoration priorities across the region to reduce overall ecosystem vulnerability to climate change. For example, NOAA's report, *Adapting to Climate Change: A Planning Guide for State Coastal Managers*, provides coastal managers with a useful landscape-based approach to help them incorporate climate change in state and local planning.²⁸

III. Overarching Principles for Climate-Smart Restoration

Before getting into specific guidance for the development of climate-smart restoration projects, we explore some overarching principles for thinking about coastal restoration in a truly climate-smart frame.

1. Look to the Future while Learning from the Past

Developing climate-smart restoration projects requires an understanding of the current and potential impacts of climate change on the ecosystems in which those projects are situated, and of the vulnerability of projects themselves to those impacts. This, in turn, requires a deeper understanding of how systems function. Relying solely on historical trends and past ranges of variability for factors such as streamflows, sediment sources, temperature regimes, and Great Lakes water levels is unlikely to be sufficient as a guide for project design. Nor can we assume that baseline conditions or reference habitats against which we can measure project success will remain static. Increasingly, we will need to incorporate projections for future conditions based on models and other sources of information. This will entail confronting two key challenges: 1) getting

information at an appropriate scale for decisions, and 2) identifying and choosing an appropriate suite of climate change scenarios to constrain project planning and implementation (this topic is addressed further in Appendix A).

That said, the importance of using projections for project design does not mean that historical information is irrelevant. Indeed, natural climatic variability and extreme events/disturbances have played a significant role in shaping our planet's ecological and human communities, and a species' or system's current and historical climatic context informs its sensitivity to future changes. Understanding how both ecosystems and societies have responded to climatic variability and disturbances provides a useful analog for how such systems might respond to changes such as more frequent flooding or drought conditions or more variable lake levels in the future.

Developing climate-smart restoration projects requires an understanding of the current and potential impacts of climate change on the ecosystems in which those projects are situated, and of the vulnerability of projects themselves to those impacts.

2. Adopt a Broader, Landscape Approach to Selecting and Managing Restoration Projects

The overarching threat of climate change underscores the value of approaching restoration from a broader, more landscape-level perspective – one that emphasizes cumulative threats as well as cumulative benefits from the restoration projects themselves. The ecological impacts associated with climate change do not exist in isolation, but combine with, exacerbate, and are exacerbated by existing stresses on our natural systems. Understanding those interactions is critical to designing effective restoration projects. Further, climate change will require that we think and plan within the context of larger spatial scales, even when our management needs are very local. For example, many species are expected to shift ranges in response to shifting climates. As a result, our existing portfolio of protected areas and wildlife management areas may no longer support the suite of species for which they had originally been established.³¹

The ecological impacts associated with climate change do not exist in isolation, but combine with, exacerbate, and are exacerbated by existing stresses on our natural systems.

3. Emphasize Restoration of Ecological Processes and Dynamic Systems

Climate-smart coastal restoration also necessitates greater emphasis on restoring the ecological processes fundamental to a dynamic, resilient coastal system, rather than recreating a snapshot from the past.³² In its most general sense, *ecological resilience* refers to the ability of a system to recover from a disturbance or change without significant loss of function.³³ Particularly in already highly-modified landscapes, achieving a fully “self-sustainable” system may not be possible. However, there are several ways in which restoration projects can achieve at least some degree of resilience.³⁴ For example, restoration efforts can seek opportunities to develop/protect habitat buffers (e.g., removing natural or anthropogenic barriers to habitat/species migration) to provide systems with greater capacity to track shifts in climate.³⁵ In areas where ecological engineering is necessary, efforts that place greater emphasis on ways to mimic ecological processes under current and future conditions may be more effective in promoting resilience of the system being restored than focusing on a particular habitat structure.³⁶

It is also important to recognize that promoting resilience from a broad perspective may not be a sufficient restoration objective. An ecosystem that is resilient to drought is not necessarily resilient to flood; one that is resilient to heat waves may not be resilient to cold snaps. Thus, a targeted approach to

building resilience should explicitly address those climatic changes and impacts that are regarded as the most significant threats to overall ecosystem function. This may be the most likely changes or impacts, the most extreme of the plausible changes or impacts, or the changes to which the system is most sensitive.

Finally, promoting resilience is not the only available adaptation strategy, and may not always be the optimal strategy. In some instances, we may want to focus on approaches to build *resistance* to climate-related stressors, which refers to the ability of a system to withstand (rather than recover from) a disturbance or change without significant loss of ecological function. Resistance strategies may be appropriate for maintaining high-value species or systems (e.g., controlling new invasive species). Increasingly, we may need to employ *transformation* strategies that anticipate and facilitate ecological transitions that reflect the changing environmental conditions (e.g., use of species or genetic material in replanting that are optimized for future, rather than historical conditions).^{37, 38}

4. Embrace Uncertainty

Perhaps most importantly, we will need to embrace decision-making under uncertainty. By its very nature, there will always be a degree of uncertainty about climate change as well as how, when, and where it will affect natural systems. Increased monitoring and research on the known and potential impacts will help close the gap in knowledge, but we will



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A targeted approach to building resilience should explicitly address those climatic changes and impacts that are regarded as the most significant threat to overall ecosystem function.

never know exactly when and where we will experience the impacts in the future. This does not mean we should not take climate change into consideration in our conservation efforts today. Rather, the very fact that there is risk – and the potential for climate change to lead to irreversible damages – necessitates precautionary action. For restoration efforts, this may mean focusing on developing *robust* projects – ones that are likely to provide benefits under multiple scenarios of future climate conditions – as well as taking an adaptive management approach to project design and implementation.³⁹ This will require greater investment in monitoring project performance over time.

IV. Planning and Designing Climate-Smart Coastal Restoration Projects



U.S. Environmental Protection Agency

The process of developing climate-smart coastal restoration projects is fundamentally no different from the process used for planning successful coastal restoration projects in general. It entails defining your restoration targets and goals; assessing

the condition of your target system and the challenges at hand; identifying and implementing appropriate restoration strategies; and managing and assessing project performance. Making coastal restoration efforts climate-smart requires looking at each of these steps through a climate change lens, mindful of the overarching principles highlighted above.

The framework illustrated in Figure 2 identifies some key steps that project planners can take to help ensure that restoration efforts are climate-smart. Each step is explained in detail throughout this document. In the short term, the first two steps will likely be predetermined, at least in a general sense, given current restoration efforts. Climate-smart planning will come into play more explicitly during the vulnerability assessment stage and in identifying specific management responses. As projects move forward, taking an adaptive management approach will be important. Ultimately, as you implement your plan and monitor your project outcomes, you may determine that additional revisions to targets, goals, and approaches will be warranted. Climate-smart restoration, like most conservation efforts, is necessarily an iterative process.

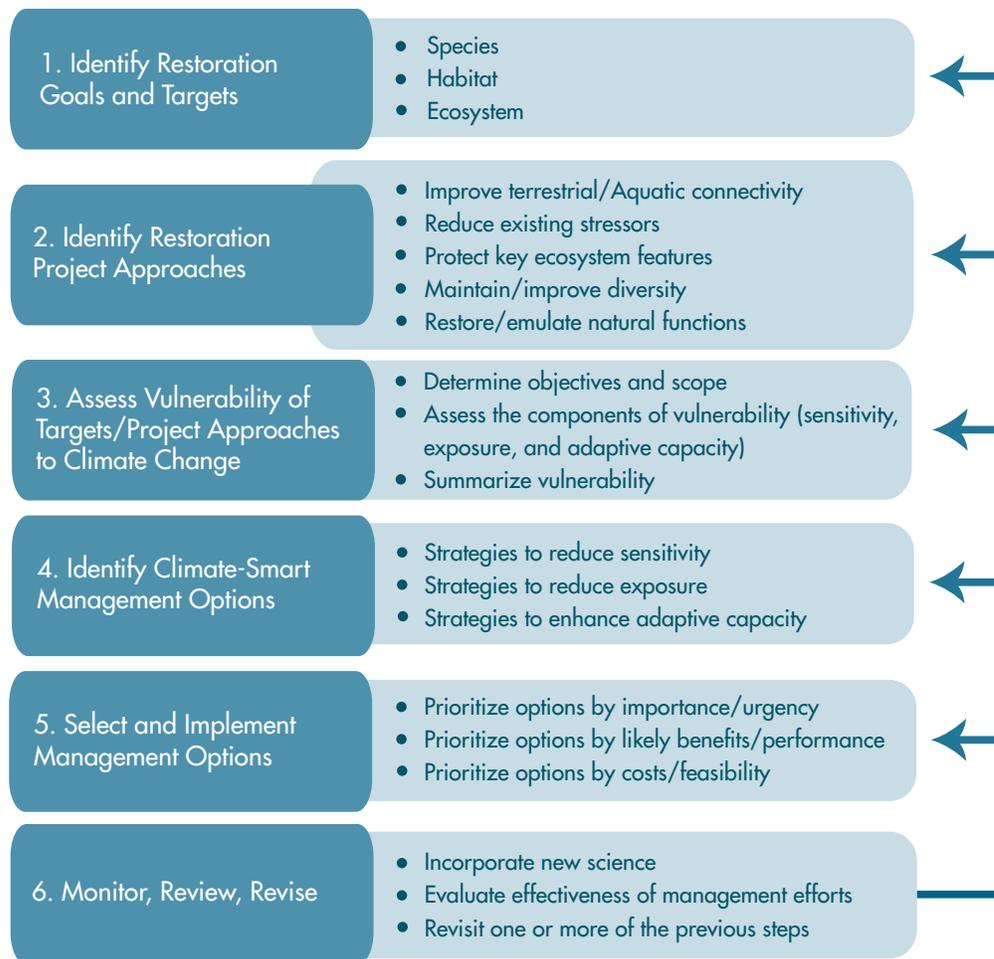


Figure 2. Framework for Developing Climate-Smart Restoration Projects

Step 1: Identify Restoration Goals and Targets

The development of any restoration project requires, first and foremost, the identification of restoration goals and targets. At a regional level, many restoration efforts currently underway are implemented, funded, or otherwise supported by existing programs such as the GLRI, which have been developed largely to deal with familiar stressors such as pollution, habitat fragmentation and

destruction, invasive species, etc. These problems remain relevant regardless of climate change; it is the combined effects of climate change and existing problems that must be anticipated and addressed in conservation and restoration.⁴⁰

As you look at your targets and goals through a climate change lens, however, some priorities may change. For example, warmer temperatures may enable a potentially problematic invasive species to expand into new areas. Project managers may decide to proactively devote additional resources toward halting the spread of this invasive species before it arrives in the

region, something they may not have chosen as a restoration priority without this knowledge. Assessing the vulnerability of your targets and goals to climate change, as described below, will help inform these decisions.



U.S. Fish and Wildlife Service

In the Great Lakes region, much of NOAA's restoration work is focused on community-based efforts to address fish and wildlife habitat-related BUIs (e.g., degradation of fish and wildlife population, loss of fish and wildlife habitat, and degradation of benthos) in U.S. Great Lakes AOCs.⁴¹ Under the GLRI, the overarching goal for Habitat and Wildlife Protection and Restoration is the protection and restoration of

ecosystems: the Great Lakes, the coastline, wetlands, rivers, connecting channels, and watersheds.⁴² The following are identified as Principal Actions to Achieve Progress in this area:

- **Improve Aquatic Ecosystem Resilience.** Protect and restore aquatic habitats for fish and wildlife populations by reconnecting habitats through corridors to enhance biological diversity, reducing sediment and nutrient inputs, restoring natural hydrological processes, improving water quality, restoring ecosystem services, and increasing populations of native fish and wildlife through coordinated management actions.
- **Maintain, Improve, or Enhance the Populations of Native Species.** Implement restoration actions identified in species recovery and management plans; quantify habitat needs for depleted migratory bird species; propagate lake trout, coaster brook trout, lake sturgeon, and other similar fingerlings for suppressed fish populations; assess fish populations; and protect and restore culturally significant species.
- **Enhance Wetlands, Wetland-Associated Uplands, and High Priority Coastal, Upland, and Inland Habitats.** Protect, restore, or enhance habitats by acquiring properties that are important to sustain fish and wildlife populations, restoring natural hydrological regimes, improving water quality, and restoring the chemical, physical, and biological integrity of ecosystems in each Great Lakes basin.
- **Identify, Inventory, and Track Progress on Great Lakes Habitats, Including Coastal Wetlands Restoration.** Assess progress toward

restoring Great Lakes habitats by establishing baseline conditions and tracking trends; highlight the importance of coastal wetland conservation and restoration by implementing a long-term coastal wetland monitoring program and enhancing the National Wetlands Inventory.

- **Restore Habitat Function in Areas of Concern.** Improve habitats in degraded urban environments and AOCs where BUIs affect ecosystem functioning by restoring habitats for native species populations and removing or isolating contaminants.

Step 2. Identify Restoration Project Approaches

The general toolbox of restoration approaches is likely to remain largely unchanged for climate-smart projects, although the risks associated with climate change may require changes in some of the assumptions that go into project design as well as the types of approaches to use. Again, climate change vulnerability assessments will help in determining whether and how certain restoration or management practices might be appropriate to ameliorate the impacts while promoting coastal restoration goals.⁴³

Climate-smart restoration underscores the importance of restoring ecological function and resilience – concepts that already are fundamental to the GLRI and other restoration initiatives.⁴⁴ As mentioned

previously, resilience is generally defined as the ability of a system to recover from a change or disturbance without significant loss of function. In the climate change adaptation literature, the discussion of how to promote resilience typically emphasizes four key objectives:⁴⁵

- Prioritizing connectivity of habitat.
- Reducing existing stressors.
- Protecting key ecosystem features.
- Maintaining biological diversity.

Arguably, these objectives are important for ecological restoration regardless of climate change. The key question is how effective these approaches are likely to be given the multitude of impacts affecting the systems being addressed, including climate change. For example, while it is widely recognized that reducing habitat fragmentation and increasing habitat connectivity are important conservation tools, climate change requires managers to look at a range of factors that could determine whether or not these measures

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will truly be effective in achieving the desired conservation outcome: are we connecting the most beneficial habitats given projections for species range shifts or the movements of individual organisms? Are our target species even likely to shift their range under climate change in the first place?⁴⁶

Similarly, climate change may require us to re-prioritize which existing stressors we address or to address them in different ways. This is not to say that we should ignore existing stressors. In some cases, focusing on those stressors may well be our



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best restoration or conservation option in the near term. For species that are already highly endangered, for example, failure to reduce or eliminate immediate threats such as habitat destruction may lead to extinction before climate change becomes a significant factor. In addition, dealing with non-climate stressors may be our only option in cases where our ability to ameliorate some of the more direct impacts of climate change, such as higher air and water temperatures, may be exceedingly difficult, if not impossible. Increasingly, however, we will likely be faced with the need to modify our priorities and actions: current allowable contaminant levels may need to be tightened for contaminants that interact with climate change; fish passage structures may become more or less important under altered streamflow regimes; critical habitat designations may need to include future as well as current population centers; and invasive species control may be more important where habitats are perturbed by extreme events.

Step 3. Assess Vulnerability of Targets/Project Approaches to Climate Change

Developing climate-smart restoration projects requires managers to go through an explicit process for bringing climate data and ecological understanding to bear on their planning.⁴⁷ A key tool for doing this is *climate change vulnerability assessment*. In this context, climate change vulnerability refers to the extent to which a species, habitat, or ecosystem that is the target of restoration efforts is susceptible to harm from climate change impacts. It also refers to the extent to which climate change impacts might influence the ultimate effectiveness of particular restoration projects in meeting one's conservation objectives. Vulnerability assessment is

not an end in itself – it is one step in the broader process of developing climate-smart strategies and projects.

Like other vulnerability or risk assessments, climate change vulnerability assessments can vary considerably in terms of scope and complexity – from general, qualitative assessments based on expert knowledge, to formalized expert elicitation processes, to highly detailed, quantitative analysis using ecological models. There is no single right approach, and greater levels of complexity do not necessarily mean greater accuracy or utility. Rather, the design and execution of an assessment must be based on a firm understanding of the user needs, the decision processes, and the availability of resources such as time, money, data, and expertise.

Appendix A provides a detailed overview of climate change vulnerability assessment, including some examples of relevant information for Great Lakes species and habitats. The following is a brief summary of the key steps and questions that restoration project planners must address to determine whether, how, and to what extent your restoration projects and goals might be vulnerable to climate change and related impacts.

A. Determine Scope and Objectives

A critical first step in conducting a vulnerability assessment is to determine your scope and objectives, including: identifying your restoration targets, goals, and approaches; defining the geographical scale of your project; and establishing your timeline (i.e., the lifespan of the project). For project-level restoration planning,

much of this will be determined under steps 1 and 2, above. Essentially, this information establishes the baseline level of vulnerability irrespective of potential effects of future climate change (i.e., it identifies the reasons the particular species, habitats, or ecosystems are targeted for restoration efforts in the first place).

B. Assess the Components of Vulnerability

The next step is to assess the components of vulnerability to climate change:

- **Sensitivity.** How and to what degree are your restoration targets and/or project approaches sensitive to climate conditions/variables? The sensitivity of a species, habitat, ecosystem, or restoration project approach reflects the degree to which that system is or is likely to be affected by or responsive to climatic changes (e.g., a species with a narrow temperature tolerance is likely to be more affected by warmer temperatures than a species with a broader temperature tolerance).



U.S. Air Force

- **Exposure.** Even if your target system is inherently sensitive to climate change, its vulnerability also depends on the character, magnitude, and rate of changes to which it is exposed (e.g., temperature and precipitation, altered streamflows). Is evidence of climate change already being observed in your planning area? How are climatic conditions projected to change in the region? Focus particularly on those climatic variables likely to be most important to your restoration target/project. The choice of which climate change scenarios to use will depend on factors such as the length of your planning horizon, the level of confidence in the projections, and the level of acceptable risk. Appendix A provides greater detail on how to determine appropriate scenarios for your assessment.

- **Adaptive Capacity.** Are systems in your planning area able to accommodate or cope with the impacts of climate change? Adaptive capacity may reflect both internal traits (e.g., mobility, plasticity) and external conditions (e.g., structural barriers, pre-existing stressors, institutional/financial restrictions).

C. Summarize Vulnerability

The final step in a vulnerability assessment is to combine your findings about sensitivity, exposure, and adaptive capacity to determine which of your conservation goals/approaches are vulnerable to climate change and why. While vulnerability is often characterized by relative values (e.g., low, medium, high), it is also important to provide more descriptive information to better inform possible adaptation approaches.

Sample Illustrative Examples of Vulnerability Assessments of Various Restoration Projects

The following tables (1-9) provide some general, hypothetical examples of how the various components of vulnerability might come into play for coastal restoration efforts supported by NOAA and others.⁴⁸

These illustrative examples include the following projects:

Table 1: Fish Passage Restoration

Table 2: Drowned River-Mouth Wetland Habitat Restoration

Table 3: Coaster Brook Trout Habitat Restoration

Table 4: Whitefish Habitat Restoration

Table 5: Invasive Species Management

Table 6: Water Quality Restoration

Table 7: Oil Spill Damage Assessment, Remediation, Restoration

Table 8: Amphibian Habitat Restoration

Table 9: Wild Rice Habitat Restoration

Much of the information included in the tables is based on a preliminary review of existing literature. There are a number of readily available studies that can provide you with information to determine one or more of the components of vulnerability for species and systems in the Great Lakes region (see Appendix B). In cases where we were unable to find relevant information, we used our best judgment. Furthermore, we did not explicitly express levels of confidence in these sample answers. Rather, *the information provided in these tables is illustrative – they do not represent comprehensive assessments for direct use by project planners. Individual projects will have unique needs that warrant a more thorough, targeted process than these examples suggest.*

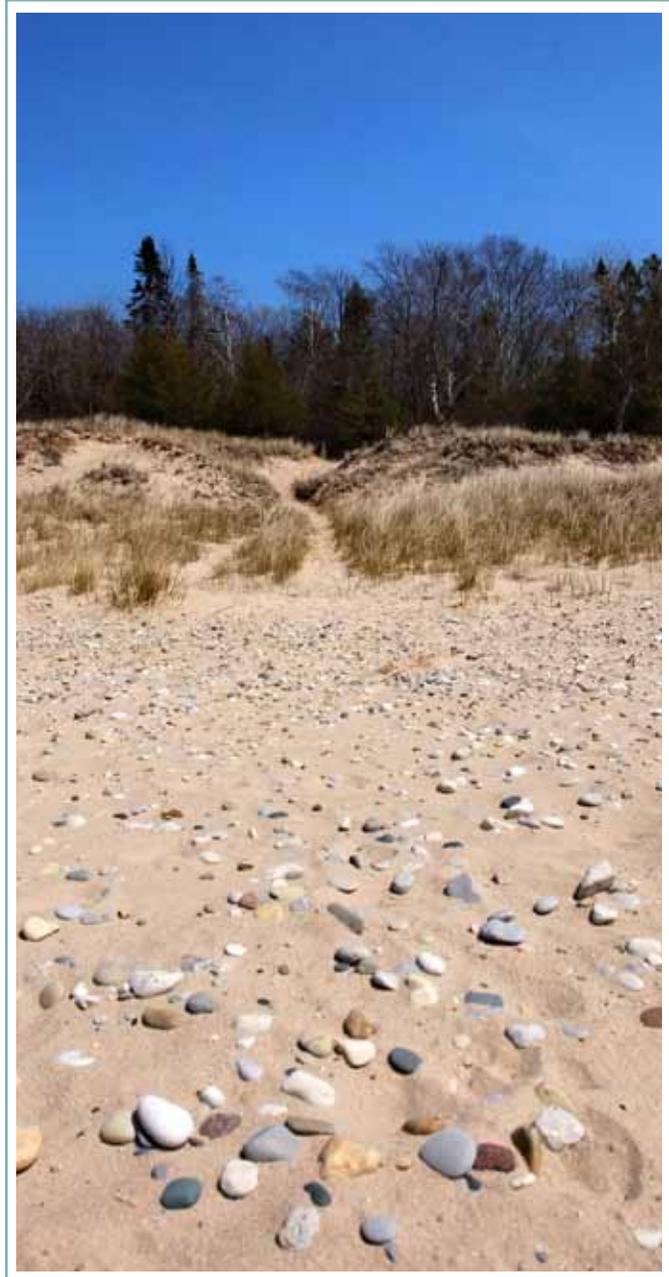
Each table examines the vulnerability of targets, goals, and approaches of various restoration projects. For every example, vulnerability is examined by a set of questions outlined below:

A. Scope and Objectives

- *What are your current restoration goals?*
- *What are your restoration targets?*
- *What is the current status of your restoration target (e.g., what factors are contributing to BUIs)?*
- *What restoration approaches are you planning/implementing to improve the status of your target?*
- *What is the expected lifetime of your project?*

B. Components of Vulnerability

- *How and to what degree is your restoration target sensitive to climate conditions/variables?*
- *How and to what degree is your restoration approach sensitive to climate conditions/variables?*
- *How are climate conditions projected to change in the area, and is there evidence of climate change already being observed in your planning area?*
- *What is your system's adaptive capacity relative to climate change?*



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C. Vulnerability Summary

- *What is the relative vulnerability of your restoration project (including your targets, goals, and approaches)? What are the primary reasons?*

Table 1. Fish Passage Restoration Project: Illustrative Vulnerability Assessment

A. Scope and Objectives	
<ul style="list-style-type: none"> What are your current restoration goals? 	Improve habitat connectivity; reduce existing stressors; restore/emulate ecosystem functions.
<ul style="list-style-type: none"> What are your restoration targets? 	Native fish species.
<ul style="list-style-type: none"> What is the current status of your restoration target (e.g., what factors are contributing to BUIs?) 	Existing dam has altered natural river flows and blocked fish passage.
<ul style="list-style-type: none"> What restoration approaches are you planning/implementing to improve the status of your targets? 	Construction of fish passage structure and flow management.
<ul style="list-style-type: none"> What is the expected lifetime of the project? 	Infrastructure elements of project are expected to last 30-50 years before they need to be repaired/ rebuilt.
B. Components of Vulnerability	
Sensitivity	
<ul style="list-style-type: none"> How and to what degree are your restoration targets sensitive to climate conditions/variables? 	Streamflows are sensitive to precipitation patterns, groundwater input (base flow), and evaporation ⁴⁹ Target fish species are sensitive to timing and volume of streamflows for migration and spawning, although sensitivity varies by species. ⁵⁰
<ul style="list-style-type: none"> How and to what degree are your restoration approaches sensitive to climate conditions/variables? 	Effectiveness of fish passage design is sensitive to changes in the extent and timing of high and/or low flows.
Exposure	
<ul style="list-style-type: none"> How are climate conditions projected to change in the area? 	Continuing trend of heavier rainfall events in fall/winter; reduced precipitation, lower streamflows/groundwater input in summer. ⁵¹
<ul style="list-style-type: none"> Is there evidence of climate change already being observed in the area? 	Heavier rainfall events are becoming more frequent. ⁵² Snowmelt and runoff are occurring earlier in the year. ⁵³
Adaptive Capacity	
<ul style="list-style-type: none"> What is your system's adaptive capacity relative to climate change? 	The existence of a dam limits the natural adaptive capacity of the river system and associated species. Adaptive capacity of various project approaches will depend on relative ability to alter project design. Changes in flow management may face constraints due to other demands for water resources in the region.
C. Vulnerability Summary	
<ul style="list-style-type: none"> What is the relative vulnerability of your restoration project (including your targets, goals, and approaches)? 	Medium/High
<ul style="list-style-type: none"> What are the primary reasons? 	Some changes in flow regimes are already occurring, and more extremes in the future may make it more difficult for fish to navigate the river barrier (e.g., low flows may make navigation around/over barrier difficult/impossible in summer; high flows may prevent passage of species that are not able to expend the necessary energy). There is relatively high adaptive capacity for this project if design takes into consideration the projected changes, but effectiveness will depend on overcoming possible management constraints.

Table 2. Drowned River-Mouth Wetland Habitat Restoration Project: Illustrative Vulnerability Assessment

A. Scope and Objectives	
<ul style="list-style-type: none"> What are your current restoration goals? 	Improved habitat connectivity; maintain/improve diversity; reduce existing stressors; restore/emulate ecosystem functions.
<ul style="list-style-type: none"> What are your restoration targets? 	Drowned river-mouth wetland habitat for multiple species.
<ul style="list-style-type: none"> What is the current status of your restoration target (e.g., what factors are contributing to BUIs?) 	Part of project area has wetland disconnected from lake influence due to existence of a dike. This has reduced habitat quality for target species.
<ul style="list-style-type: none"> What restoration approaches are you planning/ implementing to improve the status of your targets? 	Construct and maintain structures to allow for optimal water level and river flow processes in diked wetland.
<ul style="list-style-type: none"> What is the expected lifetime of the project? 	Infrastructure expected to last 30-50 years before it needs to be repaired/rebuilt.
B. Components of Vulnerability	
Sensitivity	
<ul style="list-style-type: none"> How and to what degree are your restoration targets sensitive to climate conditions/variables? 	These wetlands are sensitive to changes in the timing, duration, and height/elevation of annual and seasonal lake water levels and river flows ⁵⁴
<ul style="list-style-type: none"> How and to what degree are your restoration approaches sensitive to climate conditions/ variables? 	Effectiveness of water flow management structures is sensitive to changes in average lake levels as well as changes in extremes in both lake levels and streamflows.
Exposure	
<ul style="list-style-type: none"> How are climate conditions projected to change in the area? 	In general, average Great Lakes water levels are projected to decline by mid-century due to a combination of increased evaporation and decreased inflow from surface and groundwater. ⁵⁵ Evapotranspiration is likely to increase in all seasons. Continuing trend of heavier rainfall events in fall/winter; reduced precipitation, lower streamflows in summer. ⁵⁶
<ul style="list-style-type: none"> Is there evidence of climate change already being observed in the area? 	The region is experiencing higher average air and lake surface temperatures and reduced duration and extent of lake ice cover/increased stratification. ⁵⁷ This is considered to be a precursor to declining average lake levels. Heavier rainfall events are becoming more frequent. ⁵⁸ Snowmelt and runoff are occurring earlier in the year. ⁵⁹

(table continued on page 22)

(table continued from page 21)

<p>Adaptive Capacity</p>	
<ul style="list-style-type: none"> What is your system's adaptive capacity relative to climate change? 	<p>Annual and perennial vegetation of marsh wetlands in undiked areas may be able to migrate in response to water level declines, depending on sediment, slope, seed bank, existence of other barriers.⁶⁰ On the other hand, changes in temperature or hydrological regime that benefit invasive species may further stress native wetland species (e.g., low water levels correlate with greater abundance of <i>Phragmites</i>).⁶¹ Adaptive capacity of various project approaches will depend on relative ability, time needed and/or resources available to alter project design if necessary.</p>
<p>C. Vulnerability Summary</p>	
<ul style="list-style-type: none"> What is the relative vulnerability of your restoration project (including your targets, goals, and approaches)? 	<p>Medium.</p>
<ul style="list-style-type: none"> What are the primary reasons? 	<p>Recent extreme low lake level events, while not necessarily linked directly to climate change, illustrate how these wetland systems are likely to respond to extreme water level change. Perturbations can alter the natural succession of plants in wetlands, which influences the species, diversity, and number of fish and wildlife a wetland can support.^{62,63,64} Ultimately, conditions may become favorable for some species and detrimental to others (e.g., shallow wetlands with greater coverage by emergent vegetation may benefit some water birds such as yellow rails but would be less favorable for other waterfowl).⁶⁵ Water flow management is sensitive to changes in lake level and streamflow; lower water levels encourage the spread of invasive plant species. There is relatively high adaptive capacity for this project if design takes into consideration the projected changes, but effectiveness will depend on the types of species restored and other management issues.</p>



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Table 3. Coaster Brook Trout Habitat Restoration Project: Illustrative Vulnerability Assessment

A. Scope and Objectives	
<ul style="list-style-type: none"> • <i>What are your current restoration goals?</i> 	Reduce existing stressors; protect key ecosystem features; maintain diversity.
<ul style="list-style-type: none"> • <i>What are your restoration targets?</i> 	Coaster brook trout habitat.
<ul style="list-style-type: none"> • <i>What is the current status of your restoration target (e.g., what factors are contributing to BUIs?)</i> 	Historical population declines due to over-fishing, habitat loss, human activities such as logging and mining, and invasive species.
<ul style="list-style-type: none"> • <i>What restoration approaches are you planning/implementing to improve the status of your targets?</i> 	Build or maintain spawning areas; mitigate siltation that may have occurred following agricultural clearing or other development; begin/continue/modify hatchery stocking, create/continue/modify restrictions on recreational harvest. ⁶⁶
<ul style="list-style-type: none"> • <i>What is the expected lifetime of the project?</i> 	Indefinite.
B. Components of Vulnerability	
Sensitivity	
<ul style="list-style-type: none"> • <i>How and to what degree are your restoration targets sensitive to climate conditions/variables?</i> 	Coaster brook trout rely on both lake and stream habitats and are sensitive to higher water temperatures and changes in oxygen levels. ⁶⁷
<ul style="list-style-type: none"> • <i>How and to what degree are your restoration approaches sensitive to climate conditions/variables?</i> 	Spawning habitat restoration efforts are likely to be sensitive to altered temperature and flow regimes.
Exposure	
<ul style="list-style-type: none"> • <i>How are climate conditions projected to change in the area?</i> 	Average lake temperatures are projected to continue to increase; average stream temperatures also are projected to increase (with localized variation due to factors such as shade, and water flow regimes). ⁶⁸
<ul style="list-style-type: none"> • <i>Is there evidence of climate change already being observed in the area?</i> 	The region is experiencing higher average air and lake surface temperatures and reduced duration and extent of lake ice cover. ^{69, 70} Heavier rainfall events are becoming more frequent. ⁷¹ Snowmelt and runoff are occurring earlier in the year. ⁷²
Adaptive Capacity	
<ul style="list-style-type: none"> • <i>What is your system's adaptive capacity relative to climate change?</i> 	Cool/cold water fish species may be able to accommodate periodic increases in water temperature if they have access to refugia such as deep pools, tributaries, or shaded riparian areas. ⁷³ Adaptive capacity of various project approaches will depend on relative ability to alter project design (e.g., costs, planning needs), potential for institutional changes to fisheries management, etc.
C. Vulnerability Summary	
<ul style="list-style-type: none"> • <i>What is the relative vulnerability of your restoration project (including your targets, goals, and approaches)?</i> 	High.
<ul style="list-style-type: none"> • <i>What are the primary reasons?</i> 	Higher lake temperatures could reduce favorable spawning habitat and juvenile incubation; longer periods of stratification in summer may limit availability of nutrients and phytoplankton; nearshore water quality could decline. ⁹ Altered streamflow regimes and higher stream temperatures will reduce quality of stream habitat. Success of stream restoration efforts is sensitive to climate change, although there is relatively high adaptive capacity for accommodating climate impacts via project design.

Table 4. Whitefish Habitat Restoration Project: Illustrative Vulnerability Assessment

A. Scope and Objectives	
<ul style="list-style-type: none"> What are your current restoration goals? 	Reduce existing stressors that inhibit spawning; restore habitat to more favorable conditions.
<ul style="list-style-type: none"> What are your restoration targets? 	Whitefish spawning habitat.
<ul style="list-style-type: none"> What is the current status of your restoration target (e.g., what factors are contributing to BUIs)? 	Excess nutrients, degraded spawning habitat, impacts from invasive species (e.g., dreissenid mussels).
<ul style="list-style-type: none"> What restoration approaches are you planning/implementing to improve the status of your targets? 	Reduce phosphorus loads and control invasive species to enhance health of spawning areas.
<ul style="list-style-type: none"> What is the expected lifetime of the project? 	Indefinite.
B. Components of Vulnerability	
Sensitivity	
<ul style="list-style-type: none"> How and to what degree are your restoration targets sensitive to climate conditions/variables? 	Whitefish are sensitive to the availability of ice cover during the spawning season, as well as sensitive to temperatures outside their optimal water ranges and changes in water quality. ⁷⁵
<ul style="list-style-type: none"> How and to what degree are your restoration approaches sensitive to climate conditions/variables? 	Efforts to address nutrient loading will be sensitive to changes in flow regimes (e.g., heavy rainstorm events may lead to greater runoff and increased pollutant loads into lake systems); invasive species controls may be sensitive to similar changing conditions.
Exposure	
<ul style="list-style-type: none"> How are climate conditions projected to change in the area? 	The duration of ice cover is projected to decline by several weeks to several months by mid- to-late century. ⁷⁶
<ul style="list-style-type: none"> Is there evidence of climate change already being observed in the area? 	Ice and snow cover and duration have decreased across the Great Lakes, more rapidly than any changes that have occurred over at least the last 250 years. ⁷⁷ Increases in near-shore water temperatures of the Great Lakes are lengthening the period of summer stratification. ⁷⁸
Adaptive Capacity	
<ul style="list-style-type: none"> What is your system's adaptive capacity relative to climate change? 	These species are likely to have relatively low adaptive capacity, as they are specialists with respect to their dependence on cold water and lake ice.
C. Vulnerability Summary	
<ul style="list-style-type: none"> What is the relative vulnerability of your restoration project (including your targets, goals, and approaches)? 	High.
<ul style="list-style-type: none"> What are the primary reasons? 	Reduced ice cover could mean greater mortality of whitefish eggs, which rely on the formation of ice over shallow waters for protection from wind and waves. Increased variability associated with climate change could make spawning/nursery conditions unfavorable for this species in some areas. ⁷⁹

Table 5. Invasive Species Management Project: Illustrative Vulnerability Assessment

A. Scope and Objectives	
<ul style="list-style-type: none"> • <i>What are your current restoration goals?</i> 	Reduce existing stressors, including sea lamprey populations.
<ul style="list-style-type: none"> • <i>What are your restoration targets?</i> 	Sea lamprey control to reduce decimation of native fish species populations.
<ul style="list-style-type: none"> • <i>What is the current status of your restoration target (e.g., what factors are contributing to BUIs?)</i> 	Sea lamprey were first observed in Lake Erie in the 1920s and have since colonized the upper lakes and contributed greatly to the decline of native salmonid populations.
<ul style="list-style-type: none"> • <i>What restoration approaches are you planning/implementing to improve the status of your targets?</i> 	Aggressive sea lamprey control programs already exist, so it is important to focus on how to enhance or improve these programs. Two ways to control lamprey population include: construction of low-head dams to block upstream migration and extensive use of lampricides in spawning tributaries.
<ul style="list-style-type: none"> • <i>What is the expected lifetime of the project?</i> 	Indefinite.
B. Components of Vulnerability	
Sensitivity	
<ul style="list-style-type: none"> • <i>How and to what degree are your restoration targets sensitive to climate conditions/variables?</i> 	Sea lamprey and host species (lake trout, whitefish) are sensitive to water temperatures. ⁸⁰ Sea lamprey thrive (both size and reproduction) in warmer temperatures while host species require colder temperatures.
<ul style="list-style-type: none"> • <i>How and to what degree are your restoration approaches sensitive to climate conditions/variables?</i> 	Effectiveness of lamprey control may be sensitive to changing conditions that affect lamprey productivity. For example, studies suggest that variations in streamflows due to rainfall events may increase risk of dilution and lead to sublethal applications. ⁸¹
Exposure	
<ul style="list-style-type: none"> • <i>How are climate conditions projected to change in the area?</i> 	Average lake/stream temperatures are projected to continue to increase, as is the length of the summer stratification period. ⁸² More-extreme precipitation events are likely.
<ul style="list-style-type: none"> • <i>Is there evidence of climate change already being observed in the area?</i> 	Average lake temperatures are increasing. ⁸³ Increases in nearshore water temperatures of the Great Lakes are lengthening the period of summer stratification. ⁸⁴ Heavier rainfall events are becoming more frequent. ⁸⁵ Snowmelt and runoff are occurring earlier in the year. ⁸⁶
Adaptive Capacity	
<ul style="list-style-type: none"> • <i>What is your system's adaptive capacity relative to climate change?</i> 	Sea lampreys appear to have been able to capitalize on changes in lake conditions in some areas as higher temperatures to increase their metabolic rate. ⁸⁷ In addition, scientists believe that longer periods of lake stratification increase the amount of time in which lake trout spend in their preferred thermal range, which is providing sea lampreys with more time to feed on this important host species. ^{88, 89}
C. Vulnerability Summary	
<ul style="list-style-type: none"> • <i>What is the relative vulnerability of your restoration project (including your targets, goals, and approaches)?</i> 	Medium.
<ul style="list-style-type: none"> • <i>What are the primary reasons?</i> 	A continued increase in lake temperatures and longer periods of stratification may exacerbate sea lamprey predation if host species are restricted to areas that overlap lamprey. As lake temperatures rise, host species may face declines due to factors additional to lamprey.

Table 6. Water Quality Restoration Project: Illustrative Vulnerability Assessment

A. Scope and Objectives	
<ul style="list-style-type: none"> • <i>What are your current restoration goals?</i> 	Reduce existing stressors; restore/emulate ecosystem functions.
<ul style="list-style-type: none"> • <i>What are your restoration targets?</i> 	Aquatic fish and wildlife.
<ul style="list-style-type: none"> • <i>What is the current status of your restoration target (e.g., what factors are contributing to BUIs?)</i> 	Hypoxia/anoxia events have long been a concern in Great Lakes waters, primarily due to phosphorus pollution.
<ul style="list-style-type: none"> • <i>What restoration approaches are you planning/ implementing to improve the status of your targets?</i> 	Reduction in anoxia/hypoxia events through efforts to reduce nutrient loading.
<ul style="list-style-type: none"> • <i>What is the expected lifetime of the project?</i> 	Indefinite.
B. Components of Vulnerability	
Sensitivity	
<ul style="list-style-type: none"> • <i>How and to what degree are your restoration targets sensitive to climate conditions/variables?</i> 	Higher lake temperatures and increased stratification can exacerbate anoxia/hypoxia events. ⁹⁰ Increased runoff into lakes during heavy precipitation events could introduce additional pollutants.
<ul style="list-style-type: none"> • <i>How and to what degree are your restoration approaches sensitive to climate conditions/ variables?</i> 	Efforts to reduce pollutants are likely to be sensitive to runoff (e.g., heavier downpours may carry more phosphorus into lake waters).
Exposure	
<ul style="list-style-type: none"> • <i>How are climate conditions projected to change in the area?</i> 	Average lake temperatures are projected to continue to increase, as is the length of the summer stratification period. Heavy precipitation events will increase in frequency and intensity.
<ul style="list-style-type: none"> • <i>Is there evidence of climate change already being observed in the area?</i> 	Increases in nearshore water temperatures of the Great Lakes are lengthening the period of summer stratification. ⁹¹ Heavier rainfall events are becoming more frequent.
Adaptive Capacity	
<ul style="list-style-type: none"> • <i>What is your system's adaptive capacity relative to climate change?</i> 	The adaptive capacity of species that may be affected by longer periods of stratification/dead zones will depend on their ability to find refugia.
C. Vulnerability Summary	
<ul style="list-style-type: none"> • <i>What is the relative vulnerability of your restoration project (including your targets, goals, and approaches)?</i> 	Medium/High.
<ul style="list-style-type: none"> • <i>What are the primary reasons?</i> 	In all lakes, the duration of summer stratification is projected to increase, adding to the risk of oxygen depletion and dead zones. ⁹² These changes could alter the dominant species found in a lake and potentially contribute to the extirpation of some fish species such as lake trout. ⁹³

Table 7. Oil Spill Damage Assessment, Remediation, Restoration: Illustrative Vulnerability Assessment

A. Scope and Objectives	
<ul style="list-style-type: none"> • <i>What are your current restoration goals?</i> 	Reduce existing stressors; restore/emulate ecosystem functions.
<ul style="list-style-type: none"> • <i>What are your restoration targets?</i> 	Affected habitat/species.
<ul style="list-style-type: none"> • <i>What is the current status of your restoration target (e.g., what factors are contributing to BUIs?)</i> 	Dealing with polluting spills of chemicals, oil, hydrocarbons, and wastes are a relatively common problem in some areas.
<ul style="list-style-type: none"> • <i>What restoration approaches are you planning/ implementing to improve the status of your targets?</i> 	Installation of containment and absorbent booms, physical clean-up of ecologically sensitive areas.
<ul style="list-style-type: none"> • <i>What is the expected lifetime of the project?</i> 	As needed, short term.
B. Components of Vulnerability	
Sensitivity	
<ul style="list-style-type: none"> • <i>How and to what degree are your restoration targets sensitive to climate conditions/variables?</i> 	If spill is located in floodplain, the area is sensitive to extreme precipitation events and flooding. Toxicity of the spill may be sensitive to temperatures. ⁹⁴
<ul style="list-style-type: none"> • <i>How and to what degree are your restoration approaches sensitive to climate conditions/ variables?</i> 	Effectiveness of barriers and absorbent booms will be sensitive to extreme events such as storms.
Exposure	
<ul style="list-style-type: none"> • <i>How are climate conditions projected to change in the area?</i> 	Continuing trend of heavier rainfall events in fall/ winter; reduced precipitation in summer; higher average temperatures.
<ul style="list-style-type: none"> • <i>Is there evidence of climate change already being observed in the area?</i> 	Heavier rainfall events and flooding are becoming more frequent.
Adaptive Capacity	
<ul style="list-style-type: none"> • <i>What is your system's adaptive capacity relative to climate change?</i> 	There may be some adaptive capacity of the coastal habitat if the spill occurs in an area that has natural buffers/ filters (e.g., dunes and beach grass). Adaptive capacity of response will depend on ability to anticipate and accommodate for possible extreme events.
C. Vulnerability Summary	
<ul style="list-style-type: none"> • <i>What is the relative vulnerability of your restoration project (including your targets, goals, and approaches)?</i> 	Low.
<ul style="list-style-type: none"> • <i>What are the primary reasons?</i> 	The increased potential for flooding during spill events is a concern, as it could pass oiled sediment and materials downstream or into neighborhoods. That said, cleaning up the initial spill is the priority regardless of climate change but should consider existing trends/conditions, especially extreme rain events.

Table 8. Amphibian Habitat Creation Project: Illustrative Vulnerability Assessment

A. Scope and Objectives	
<ul style="list-style-type: none"> What are your current restoration goals? 	Improve habitat connectivity; restore/emulate ecosystem functions.
<ul style="list-style-type: none"> What are your restoration targets? 	Native amphibian species, floodplain pool habitat.
<ul style="list-style-type: none"> What is the current status of your restoration target (e.g., what factors are contributing to BUs?) 	River modifications (e.g., channelization and filling, reduction in riparian vegetation) have reduced the quality and availability of seasonal and permanent floodplain pools used as breeding habitat.
<ul style="list-style-type: none"> What restoration approaches are you planning/ implementing to improve the status of your targets? 	Constructing floodplain pools, with connection to associated stream.
<ul style="list-style-type: none"> What is the expected lifetime of the project? 	Infrastructure expected to last 30-50 years before it needs to be repaired/rebuilt.
B. Components of Vulnerability	
Sensitivity	
<ul style="list-style-type: none"> How and to what degree are your restoration targets sensitive to climate conditions/variables? 	Timing and quantity of water available for pond habitat is sensitive to flow regimes. Water temperatures in pools are sensitive to changes in air temperatures. Many amphibian species are sensitive to changes in temperature and/or precipitation. ⁹⁵
<ul style="list-style-type: none"> How and to what degree are your restoration approaches sensitive to climate conditions/ variables? 	Effectiveness of project design will be sensitive to consideration of future streamflows and temperatures.
Exposure	
<ul style="list-style-type: none"> How are climate conditions projected to change in the area? 	Continuing trend of heavier rainfall events in fall/winter; earlier peak flows in spring; reduced precipitation in summer; higher average temperatures.
<ul style="list-style-type: none"> Is there evidence of climate change already being observed in the area? 	Greater extremes in precipitation events in the region as well as earlier peak snowmelt are altering the timing and volume of streamflows.
Adaptive Capacity	
<ul style="list-style-type: none"> What is your system's adaptive capacity relative to climate change? 	Availability of refugia from high temperatures and altered flows will enhance adaptive capacity.
C. Vulnerability Summary	
<ul style="list-style-type: none"> What is the relative vulnerability of your restoration project (including your targets, goals, and approaches)? 	Medium.
<ul style="list-style-type: none"> What are the primary reasons? 	Changes in the timing of runoff may reduce availability of water inputs to floodplain pools at key times for amphibian breeding; higher temperatures and increased drought conditions in summer may adversely affect these temperature-sensitive species. ⁹⁶ Certain habitat features may provide refugia.

Table 9. Wild Rice Habitat Restoration Project: Illustrative Vulnerability Assessment

A. Scope and Objectives	
<ul style="list-style-type: none"> • <i>What are your current restoration goals?</i> 	Reduce existing stressors; restore/emulate ecosystem functions.
<ul style="list-style-type: none"> • <i>What are your restoration targets?</i> 	Wild rice habitat for harvest/wildlife conservation.
<ul style="list-style-type: none"> • <i>What is the current status of your restoration target (e.g., what factors are contributing to BUIs?)</i> 	Changes in hydrology due to dams/dikes, road construction; loss of vegetation cover to coastal development; invasive species encroachment (e.g., purple loosestrife). ⁹⁷
<ul style="list-style-type: none"> • <i>What restoration approaches are you planning/implementing to improve the status of your targets?</i> 	Construction of water flow control structures; periodic beaver dam removal to maintain optimal water levels; sowing wild rice seeds.
<ul style="list-style-type: none"> • <i>What is the expected lifetime of the project?</i> 	Indefinite.
B. Components of Vulnerability	
Sensitivity	
<ul style="list-style-type: none"> • <i>How and to what degree are your restoration targets sensitive to climate conditions/variables?</i> 	Wild rice habitats are sensitive to changes in the timing, duration, height/elevation of annual and seasonal lake water levels and water flows. ⁹⁸
<ul style="list-style-type: none"> • <i>How and to what degree are your restoration approaches sensitive to climate conditions/variables?</i> 	Effectiveness of water flow management structures is sensitive to changes in average lake levels as well as changes in extremes.
Exposure	
<ul style="list-style-type: none"> • <i>How are climate conditions projected to change in the area?</i> 	In general, average Great Lakes water levels are projected to decline by mid-century due to a combination of increased evaporation and decreased inflow from surface and groundwater. ⁹⁹ Evapotranspiration is likely to increase in all seasons. Continuing trend of heavier rainfall events in fall/winter; reduced precipitation, lower streamflows in summer. ¹⁰⁰
<ul style="list-style-type: none"> • <i>Is there evidence of climate change already being observed in the area?</i> 	The region is experiencing higher average air and lake surface temperatures and reduced duration and extent of lake ice cover/increased stratification. ¹⁰¹ This is considered to be a precursor to declining average lake levels. Heavier rainfall events are becoming more frequent. ¹⁰² Snowmelt and runoff are occurring earlier in the year. ¹⁰³
Adaptive Capacity	
<ul style="list-style-type: none"> • <i>What is your system's adaptive capacity relative to climate change?</i> 	Adaptive capacity over the long term is somewhat limited, as wild rice generally prefers minimal annual fluctuations in water level and stable or gradually receding water levels during the growing season. ¹⁰⁴
C. Vulnerability Summary	
<ul style="list-style-type: none"> • <i>What is the relative vulnerability of your restoration project (including your targets, goals, and approaches)?</i> 	Medium.
<ul style="list-style-type: none"> • <i>What are the primary reasons?</i> 	Access for human harvest may be limited during extreme low water events. Greater fluctuations in lake levels in the near term and decreases in average levels over the longer term could make current habitat areas unfavorable. Deep or flooding waters in early spring could delay germination of seed, leading to crop failures. Lower water levels late in summer could lead to more competition with other shallow water species. Long-term reductions in average lake levels may contribute to loss in wild rice habitat overall. ^{105, 106}

Step 4. Identify Climate-Smart Management Options

Once you have a sense of how climate change and related impacts are likely to affect your particular restoration targets and objectives and what the primary sources of vulnerability are, the next step is to develop a possible strategy or set of strategies to achieve your overarching conservation goals in the face of climate change. At this stage, be creative rather than selective. Information on the various



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components of vulnerability can guide the identification of possible conservation/restoration decisions to reduce that vulnerability. This might include efforts to reduce sensitivity, reduce exposure, and/or increase the adaptive capacity of your restoration target. For example:

- A strategy to reduce the sensitivity of a riverine wetland being restored might be to plant a diversity of species that can tolerate a range of flow conditions and disturbances (i.e., flooding and drought).

- A strategy to reduce the exposure of a target cold-water fish species facing increases in stream temperatures might be to identify and protect areas of potential cold-water refugia or enhance riparian vegetation.

- A measure to improve the adaptive capacity of a coastal marsh to withstand greater extremes in lake levels might be to remove existing barriers that limit the ability of the marsh to migrate. Another strategy could be to design coastal marsh water management structures to facilitate optimal marsh conditions under a range of hydrologic extremes.

Similarly, it may be possible to identify specific actions to address one or more of the factors contributing to vulnerability of your particular restoration approach. For example:

- Designing fish passage structures that are effective under projected future river flow regimes will reduce the sensitivity and/or increase the adaptive capacity of that project to such changes.
- You may be able to reduce exposure of a culvert project to extreme flooding by also restoring currently impervious areas upstream to more pervious systems.

There are numerous examples of management strategies that can help address climate change in coastal restoration. It is important to recognize that, to date, much of the literature on adaptation options for species and ecosystem management focus on general principles rather than specific, actionable measures.¹⁰⁷ Often, these include: reduce other, non-climate stressors; manage

for ecological function and protection of biological diversity; establish habitat buffer zones and wildlife corridors; implement proactive management and restoration strategies; and increase monitoring and facilitate management under uncertainty.¹⁰⁸ While these measures are intuitively correct, applying them in practice, especially for specific, on-the-ground restoration, requires consideration of some of the unique features and systems that influence your particular project site.¹⁰⁹

For example, streams across the U.S. Great Lakes Basin exhibit considerable seasonal, temporal, and geographical diversity.¹¹⁰ Trends during the mid- to late-20th century indicate that annual yield (streamflow per unit watershed area) was greatest from watersheds with greater topographic relief and forest cover, while February yield was greatest from small, lower elevation watersheds having a smaller portion of wetland area. Understanding these trends can assist in evaluating potential future changes relevant for a particular project area. Similarly, there are a number of different factors that determine stream temperatures (e.g., catchment topography, tributary inflow, the interface between surface and groundwater, and riparian tree cover).¹¹¹ Understanding the relative role of each of these factors can help determine potential options for moderating rising stream temperatures due to climate change.

Table 10 (page 32) identifies possible adaptation options for the cases highlighted in the vulnerability assessment section, above. These illustrative examples offer generalized management options, although we recognize that greater detail will be necessary for real life application. We would like to emphasize that these are

only a sampling of adaptation options. We encourage you to also develop some of your own based on your specific project vulnerabilities, goals, and approaches.



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Table 10. Linking Adaptation to Vulnerability: Potential Adaptation Options for Restoration Projects from Tables 1 – 9

Restoration Project	Relevant Vulnerabilities to Climate Change	Potential Adaptation Options
1. Fish Passage Restoration	<p>Medium/High.</p> <p>Some changes in flow regimes are already occurring, and more extremes in the future may make it more difficult for fish to navigate the river barrier (e.g., low flows may make navigation around/over barrier difficult/impossible in summer; high flows may prevent passage of species that are not able to expend the necessary energy).</p>	<p>Design fish passage based on projected low/high flow levels as well as shifts in timing of flows to at least mid-century, based on expected lifespan of infrastructure. Consider benefits to multiple species.</p>
2. Drowned River-Mouth Wetland Habitat Restoration	<p>Medium.</p> <p>Heavy rainfall events may contribute to upstream erosion and additional sediment loading in the lake if runoff is by-passed around the diked wetland area. Perturbations can alter the natural succession of plants in wetlands, which influences the species, diversity, and number of fish and wildlife a wetland can support. Ultimately, conditions may become favorable for some species and detrimental to others (e.g., shallow wetlands with greater coverage by emergent vegetation may benefit some water birds such as yellow rails but would be less favorable for waterfowl).</p> <p>In terms of the restoration approach, water flow management is sensitive to changes in lake level and streamflow; lower water levels encourage the spread of invasive plant species.</p>	<p>Design restoration infrastructure that has potential to accommodate high variability in lake levels and streamflows over the short term and lower average lake levels over the longer term. Increase awareness of possible spread of new invasive species. Timing of dewatering and reflooding of managed wetlands should consider the diverse needs of target species under a changing climate (e.g., facilitate flooding of key waterfowl areas during drought or low lake level events). Plans also should consider costs of maintaining/adapting water control infrastructure under changing conditions.</p>
3. Coaster Brook Trout Habitat Restoration	<p>High.</p> <p>Higher lake temperatures could reduce favorable spawning habitat and juvenile incubation; longer periods of lake stratification in summer may limit availability of nutrients and phytoplankton; nearshore water quality could decline. Altered streamflow regimes and higher stream temperatures will reduce quality of stream habitat.</p>	<p>Increase areas of riparian vegetation over open water and connecting stream channels to moderate temperatures. Add woody debris or other shade-providing in-stream materials. Create adjacent cool, deep pools to provide refugia.</p>

(table continued on page 33)

(table continued from page 32)

<p>4. Whitefish Habitat Restoration</p>	<p>High.</p> <p>Reduced ice cover could mean greater mortality of whitefish eggs, which rely on the formation of ice over shallow waters for protection from wind and waves. Increased variability associated with climate change could make spawning/nursery conditions unfavorable for this species in some areas. Measures to ameliorate loss of ice cover are likely to be limited.</p>	<p>Construct spawning areas with as little surface area as possible so that ice will remain and thicken. Reduce water temperatures by shading waterways. Redouble efforts to reduce phosphorus loading. Consider possible upstream/upland actions that enhance habitats to filter nutrients. Restoration efforts may require looking for alternative spawning sites in areas that might provide refugia and protection during low ice cover years.</p>
<p>5. Invasive Species Management (Sea lamprey control)</p>	<p>Low/Medium.</p> <p>A continued increase in lake temperatures and longer periods of stratification may exacerbate sea lamprey predation.</p>	<p>Increase sea lamprey control efforts in areas of high lake temperatures. Initiate early detection/rapid response measures.</p>
<p>6. Water Quality Restoration</p>	<p>Medium/High.</p> <p>In all lakes, the duration of summer stratification is projected to increase, adding to the risk of oxygen depletion and dead zones. These changes could alter the dominant species found in a lake and potentially contribute to the extirpation of some fish species such as lake trout.</p>	<p>Redouble efforts to reduce nutrient loads, with consideration of changes in precipitation/flow regimes. Identify and protect possible areas of refugia from thermal stratification.</p>
<p>7. Oil spill Damage Assessment, Remediation, Restoration</p>	<p>Low.</p> <p>The increased potential for flooding during spill events is a concern, as it could pass oiled sediment and materials downstream or into neighborhoods. Cleaning up the initial spill is the priority regardless of climate change but should consider existing trends/conditions.</p>	<p>Design oil barriers and absorbent booms to accommodate more extreme flood events given recent trends.</p>

(table continued on page 34)

(table continued from page 34)

<p>8. Amphibian Habitat Restoration</p>	<p>Medium.</p> <p>Changes in the timing of runoff may reduce availability of water inputs to floodplain pools at key times for amphibian breeding; higher temperatures and increased drought conditions in summer may adversely affect these temperature-sensitive species. Success of habitat restoration efforts is sensitive to climate change, although there is relatively high adaptive capacity for accommodating climate impacts via project design.</p>	<p>Location/design of pool connections to the mainstream will need to consider altered flow regimes; depth of constructed pools may need to be altered to provide additional refugia; consider enhancing forest cover for summer habitat to help modify temperatures.</p>
<p>9. Wild Rice Habitat Restoration</p>	<p>Medium.</p> <p>Access for human harvest may be limited during extreme low water events. Greater fluctuations in lake levels in the near term and decreases in average levels over the longer term could make current habitat areas unfavorable. Deep or flooding waters in early spring could delay germination of seed, leading to crop failures. Lower water levels late in summer could lead to more competition with other shallow water species. Long-term reductions in average lake levels may contribute to loss in wild rice habitat overall.</p>	<p>Management of wild rice habitat may require great consideration of extreme events, including protecting areas against excessive flooding and aggressively controlling invasive species in low level periods. Long term efforts may include planting species in new areas.</p>



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Dealing with Uncertainty in Developing Climate-Smart Restoration Projects – A Role for Scenario-Based Planning

As highlighted in Overarching Principles, resource managers often must make conservation decisions under uncertainty, particularly where information about future conditions must be considered. This is true not just for climate change, but for factors such as land use, population trends, and invasive species as well. Some management responses will be effective in meeting conservation goals under a range of potential climate futures, while others may need to be tailored to more specific conditions.¹¹² When future conditions are fairly certain, it makes sense to ask: Which actions will produce the single best outcome? When there is significant uncertainty about future conditions, answering that question becomes increasingly difficult because the answer depends on which future comes to pass. In such situations it may make more sense to ask: Which actions give me the best chance of an acceptable outcome? This approach is called robust decision making; it is essentially a bet-hedging strategy. Rather than maximizing the chance of the single best outcome, it seeks to maximize the likelihood of an acceptable outcome. One tool that can help you navigate through such decisions is scenario-based management planning.

Scenario-Based Management Planning is based on explicitly identifying a suite of plausible futures and exploring

Scenario-Based Management Planning is based on explicitly identifying a suite of plausible futures and exploring management options across that suite of futures.

management options across that suite of futures. Just as the use of a range of scenarios (including not just climate change but ecological and societal responses to it) can help address inherent uncertainty in assessing vulnerability, they also can provide a useful framework for informing possible climate-smart restoration options,

particularly in cases where the levels of uncertainty about potential future conditions are especially high and uncontrollable.¹¹³

The goal here is to consider a broad range of possible responses to the array of future scenarios, and what management or restoration mechanisms you can put into place that will allow you the maximum likelihood of success and flexibility given the array of possible futures.

Scenarios, at their simplest, are

descriptions of some plausible future. They are not predictions or forecasts, are not necessarily limited to the climatic changes themselves, and scenario planners make no assumptions about which scenario is most likely (if you knew which was most likely, you would not need scenario planning).

Scenario planning exercises typically use around three to five scenarios. Ideally, they will: 1) bracket the range of plausible futures, and 2) highlight those elements of uncertainty most important to management and planning outcomes. “Bracketing the range of plausible futures” does not mean simply choosing several values along a single continuum; ideally the scenarios will represent divergent possibilities along two or more axes. Having developed the scenarios, managers and planners then brainstorm possible management options

Box 1. Coastal Restoration under Uncertainty: The Case of Great Lakes Water Levels

Addressing possible changes in Great Lakes water levels will no doubt be one of the major factors under consideration when planning climate-smart restoration, as the implications for greater extremes in water level fluctuations as well as possible changes in long term averages are significant for both project design and ultimate conservation objectives. While there is moderate confidence among scientists that Great Lake water levels will decline, on average, toward the latter half of this century (see Figure 3), it is not so clear cut in the shorter-term.¹¹⁴ Under a handful of plausible scenarios, water levels in some lakes may even increase.^{115, 116} Certainly, this makes restoration planning for the next few decades somewhat tricky.

Despite uncertainty in determining an overall trend, however, lake levels themselves will continue to fluctuate seasonally and annually, as they have historically. Great Lakes water levels are influenced by several natural and anthropogenic factors, including climatic variability. Lake levels tend to decline during periods of high air temperatures and low ice cover and rise during periods with cooler, wetter conditions.¹¹⁷ It is also important to recognize that the water levels of Lake Superior and Lake Ontario are formally regulated.

To a certain extent, both coastal habitats and human communities are adapted to seasonal and interannual fluctuations in lake levels, within a certain range, duration, and rate of change.¹¹⁸ Understanding how different wetland types respond to these fluctuations can help inform proactive restoration responses under a range of potential future conditions.¹¹⁹ For example, coastal marshes adapt more readily to lower levels than swamps because their vegetation can establish itself more quickly.¹²⁰ If climate change contributes to a decline in the mean annual water level, as some models suggest, restoration efforts may need to include more hands-on measures to facilitate swamp regeneration. On the other hand, wetlands in gradually sloped, open shores may have more room to migrate upland during higher levels – or shoreward during lower levels – than those in enclosed bays and in areas with natural or human barriers.¹²¹ Given either of these potential scenarios, a robust restoration approach might be to remove and/or prevent coastal armoring or other infrastructure to enable habitats to shift in response to fluctuating water levels and then monitor the situation to determine when/where swamp regeneration efforts might be warranted in the future.

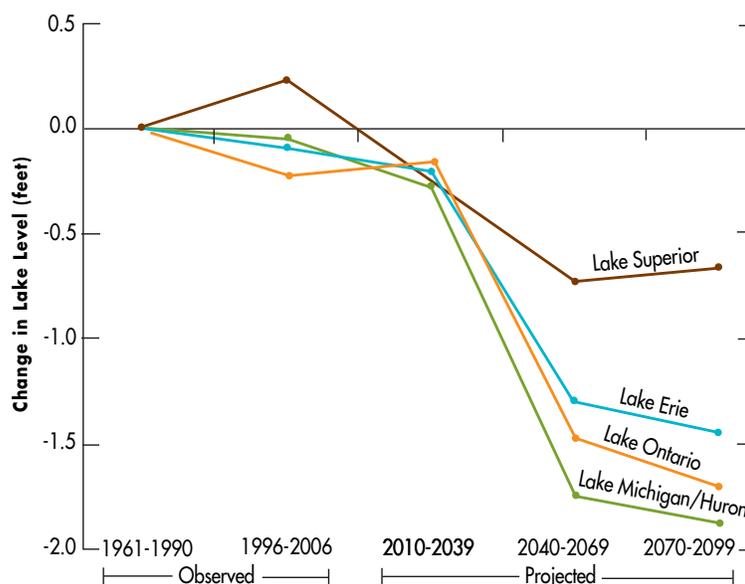


Figure 3. Average Great Lakes levels depend on the balance between precipitation and corresponding runoff in the Great Lakes Basin and evaporation and outflow. Under a lower emissions scenario (IPCC B1), (not shown here), little change is projected in lake levels over the coming century. This graphic shows projected changes under the higher (IPCC A1FI) scenario, which suggest average lake level decreases on the order of 0.5 up to nearly 2.0 feet towards the end of the century.¹²² See Appendix A for more information on the IPCC emissions scenarios.

and look at the performance of those options across all scenarios. Are there management approaches that are effective in all scenarios? Are there management options that are highly effective in one but disastrous in others? As you go through this exercise, you can highlight areas where uncertainty about climate change or the system's response to it is more or less important. Box 1 provides a simplified example of how scenario-based planning might inform restoration in the face of changing Great Lakes water levels.

Step 5. Select and Implement Management Options

Having identified possible management options for your project, it is time to choose which ones to implement. Your choice may depend on a range of factors, depending on your particular needs, interests, and resources. One or more of the following criteria will likely be important:¹²³

- **Importance.** What is at stake if you do not do anything? Are there unique or critical resources whose vulnerability should be reduced?
- **Urgency.** What are the costs of delaying action, both in terms of what you might lose and in terms of what it would cost to implement later rather than now?
- **No regrets* and co-benefits.** Do the benefits (including non-climate-related benefits) exceed the cost of

implementation? Will there be significant beneficial outcomes even if the adaptation benefits do not pan out as expected?

- **Economic efficiency.** What are the expected benefits of this project relative to using the same resources elsewhere? Are there possibilities to pool resources by engaging other stakeholders?
- **Cost.** How costly will the strategy be in terms of time, money, or other resources?
- **Unintentional effects on climate change.** Will the suggested action increase the emission of greenhouse gases, or lead to undesirable changes in the local or regional climate?
- **Performance under uncertainty.** What is the project's likely performance across the range of plausible changes in climate for your region?
- **Equity.** Does the project benefit some people, places, or interests at the expense of others? Will this project have strong negative effects on any people, places, or interest?
- **Institutional feasibility.** Is the proposed project possible given existing institutions, laws, and regulations? To what degree is the public likely to accept the project?
- **Technical feasibility.** Is the project technically possible to implement? Do we have or can we access the necessary tools and other resources?

* "No regrets" actions can be defined as actions that meet existing priority conservation needs but also address climate change; this term is also used to refer to actions that are robust across multiple climate change scenarios.



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- **Consistency.** Is the proposed project consistent with existing national, state, community, or private values, goals, and policies?

Designing an implementation plan for a climate-smart project will be very similar to developing one for any project. The steps can be as simple as outlining: 1) who is responsible for each action of the project and for overseeing the project; 2) what are the anticipated resources (e.g., financial, staff, and technical) needed for each action and are they secured; and 3) the timeline for each action. An implementation plan could also include information on communication strategies with stakeholders and/ or the public, if necessary.

Step 6. Monitor, Review, Revise

Because climatic changes, their impacts, and the effectiveness of various management options are uncertain, monitoring will be especially important. Monitoring may require significant commitment and resources, but it is likely to reduce costs stemming from climate change-related surprises. Monitoring allows for testing project assumptions and evaluating effectiveness of project actions (e.g., about how the system in question will respond to climate change, what climate changes may happen, and the effects of particular management actions). In turn, monitoring results allow project managers to refine project goals or actions as needed – a fundamental step in adaptive management (see Box 2).¹²⁴

While monitoring is not a new concept for restoration projects, climate-smart monitoring does entail some new ways of thinking about some of the key elements of your monitoring approach. The Estuary Restoration Act, for example, identifies five key elements critical to monitoring restoration projects:¹²⁹

1. Monitoring parameters must be directly linked to the goals established for the project and/or the restoration of the watershed as a whole.
2. Methods for evaluating results must be established (for example, statistical tests of hypotheses, trend analysis, or other quantitative or qualitative approaches) that directly relate to the goals for the project and/or watershed.
3. To establish initial conditions for each measure included in the monitoring plan, pre-construction or pre-design (baseline) monitoring must occur.
4. Project sites should be compared to a reference site or historical data representing a reference condition in order to evaluate progress toward reaching goals.
5. Monitoring must be conducted in a timely fashion with a frequency and length of time appropriate to each parameter in the context of project goals and the status of the project.

In thinking about each of these five elements for developing a monitoring plan, there are several key places where it will be imperative to integrate climate change considerations and variables. For example, when establishing initial baseline conditions, it will be important to

consider the fact that historical conditions and trends may no longer be sufficient. Similarly, the choice of reference sites and conditions against which to measure progress will need to factor in the potential impacts climate change will have on that site over time. Finally, it will be increasingly important for restoration project managers to monitor conditions over the long term, which will require a commitment of time, effort, and resources.

Box 2. Adaptive Management and Climate-Smart Restoration – New Impetus for a Familiar Concept

Adaptive management is defined as a systematic approach for improving resource management by learning from management outcomes.¹²⁵ It is useful not only when the future is uncertain, but when there is uncertainty about which management approach is best or how the system being managed functions even under today's conditions. Although it provides a mechanism for natural resource managers and other decision makers to develop restoration or conservation projects with incomplete information, simply picking up one management approach and adjusting it as needed is not, in the narrow sense, adaptive management. True adaptive management involves exploring alternative ways to meet management objectives, predicting the outcomes of alternatives based on the current state of knowledge, implementing one or more of these alternatives, monitoring to learn about the impacts of management actions, and then using the results to update knowledge and adjust management actions.¹²⁶ Adaptive management may be particularly useful in cases where immediate action is required to address short-term and/or potentially catastrophic long-term consequences, such as the collapse of important ecosystem services, or where management actions are likely to have no regrets near-term benefits.^{127, 128}



Michigan Sea Grant

V. Conclusion

Climate change is a universal reality that can no longer be ignored. The long-term success of conservation efforts, in this case restoration of coastal habitats in the Great Lakes, is dependent on accounting for climate change in project objectives, design, and execution. In the interest of maximizing success with utilizing limited resources, NOAA and many other government agencies across the country are beginning to require the consideration of climate change in conservation efforts.

Successful restoration in a changing climate requires learning from past conservation experiences, while at the same time accounting for how the climate will change and how these changes will potentially impact target conservation areas.

Successful resource managers will be those who consider dynamic changes in climate rather than supposing future conditions similar to past climate.

Given that species will respond in individualistic ways to climate change, ecological communities will not remain intact. Accordingly, it may no longer be effective or appropriate to manage systems based on a paradigm of maintaining some pre-existing condition, or restoring species or habitats to a previous desired state. This is all the more important given the uncertainty about future conditions, as well as the likely greater extremes in various climatic factors (such as temperatures and rainfall events).

Climate-smart restoration follows the same basic principles of any good management system, which includes: defining goals, assessing current status and challenges, identifying and implementing appropriate strategies, and managing and assessing project performance. Projects become climate-smart when at each step of the process the potential effects of climate change are considered as another factor.

While a diversity of management techniques exist, a changing climate is likely to increase the importance of certain priority approaches, including maintaining or re-establishing connectivity of habitats, reducing key existing stressors, protecting key ecosystem features, and maintaining diversity. These approaches are likely to be particularly effective at providing fish, wildlife, and plants with the greatest opportunity to survive climate change and thus meet appropriate conservation objectives.

Assessment of climate change impacts at the various stages of management requires information on projected climate changes and an assessment of those changes on existing species, habitats, and conservation objectives. Modeling and expert opinion are both options to find this information, either alone or combined. Once likely impacts are assessed, then managers have the means by which to adjust conservation objectives if necessary, and select appropriate management techniques that are likely to be most effective in light of expected climate impacts. As is necessary in any good management system, monitoring of results and adjustment of management techniques to account for lessons learned, and now for continuing changes in climate, are necessary.

Climate change neither renders past conservation efforts useless nor precludes continuing restoration efforts. Instead, we must take climate change into consideration to improve our conservation successes and protect our restoration investments.



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Projects become climate-smart when at each step of the process the potential effects of climate change are considered as another factor.

Appendix A. Vulnerability Assessment

A Key Tool for Climate-Smart Restoration

Climate change vulnerability assessments provide an essential tool for informing the development of climate change adaptation plans and strategies. There is no single right approach to vulnerability assessment that applies to all situations. Rather, the design and execution of your assessment may depend on a host of factors, including availability of already existing information, the level of expertise, time and budget constraints, and so on. For example, while there are a growing number of models available that can project the impacts of climate change on plant and animal ranges, the availability to conduct more detailed analyses such as modeling the dynamic ecological responses among diverse species within and among ecosystems is still relatively limited. In many cases, focusing

quantitative assessments more broadly on habitat changes and then applying qualitative assessments of potential species responses may be the best approach given existing information. Additional studies can then be undertaken as information and resources allow.

Components of Vulnerability

Vulnerability to climate change, as it is commonly defined, has three principal components: sensitivity, exposure, and adaptive capacity (see Figure A.1).¹³⁰ Understanding these individual components of vulnerability (whether explicitly or implicitly) is important in that it can help project planners identify more clearly which of your target species, habitats, and/or ecosystems are vulnerable to climate change and, perhaps more importantly, *why* they are vulnerable.

- **Sensitivity.** Sensitivity is the degree to which a system (whether built, natural, or human) is or is not likely to be affected by or responsive to changes in climate and/or its related impacts.¹³¹ Sensitivity of a particular species may depend on innate physiological or biological variables. For example, a species with a narrow temperature tolerance range may not be able to survive increases in the

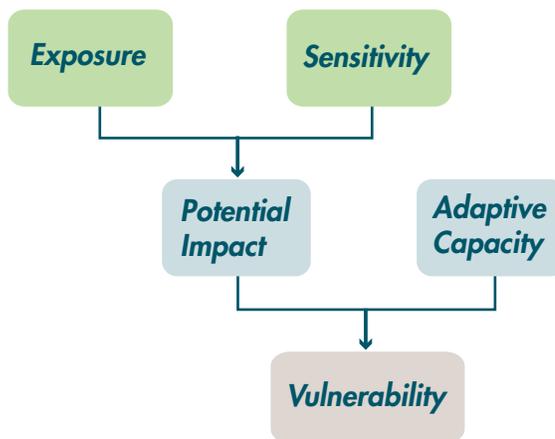


Figure A-1. Key components of vulnerability, illustrating the relationship among exposure, sensitivity, and adaptive capacity.

average temperature of its habitat due to climate change. That species is therefore considered “sensitive” to at least one element of climate change, higher average temperature. Sensitivity may also be a factor of specific physical or ecological factors. For example, a local river habitat that depends on snowmelt to maintain sufficient instream flows for fish is likely to be sensitive to reductions in average snowpack due to climate change, as well as to changes in the timing and intensity of precipitation.

- **Exposure.** Even if a particular species or system (human or natural) is inherently sensitive to climate change, its vulnerability also depends on the character, magnitude, and rate of changes to which it is exposed. For example, a specific population of a temperature-sensitive species may inhabit an area likely to be sheltered from rapid temperature increases, such as a north-facing, highly vegetated forest or high-elevation headwater stream (i.e., refugia). In such instances, the population may have a lower vulnerability than others of its species given its lower level of exposure. The use of projections at various scales as well as understanding current factors creating climatic differences across the land- or waterscape can help managers get a sense for where and how much change might be expected to affect a given conservation target.

- **Adaptive Capacity.** Adaptive capacity refers to the ability of a species or system to accommodate or cope with climate change impacts with minimal disruption. Broadly, adaptive capacity reflects both particular internal traits, such as the ability of a species to move in search of more favorable habitat conditions, adapt evolutionarily, or



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modify its behavior as climate changes, and external conditions, including the existence of structural barriers such as urban areas, bulkheads, or dikes that may limit the ability of that species or habitat to move.

The distinctions among sensitivity, exposure, and adaptive capacity are not always clean. Species mobility, for example, could reasonably be included in all categories. There are no hard-and-fast rules for where each of these components should explicitly fit as part of the overall vulnerability assessment. However, explicitly considering all three components of vulnerability may be particularly useful for informing management responses, especially when the influence of other stressors (e.g., overharvest, increased impervious surfaces) are evaluated.

Depending on the scope and nature of your project, assessing sensitivity or vulnerability to climate change could range from a less involved “thought exercise” up to a process that involves commissioning new model results. No

matter what level of complexity your assessment entails, the following are key steps to guide the process:¹³²

1. Determine objectives and scope.
2. Assess components of vulnerability.
3. Summarize vulnerability

Key Steps for Climate Change Vulnerability Assessment

A. Determine Objectives and Scope

Assessment Targets

A critical first step in conducting a vulnerability assessment is to define your specific restoration targets, goals, and approaches. First, consider relevant mandates, goals, and objectives that already exist. As highlighted in Section II, many of these goals and objectives have been identified under the GLRC Strategy and the GLRI. From here, you can identify your relevant assessment targets (i.e., species, habitats, and/or ecosystems of concern). For example, one of your restoration objectives may be to restore connectivity of tributary spawning habitat for native fish species in a particular AOC. To determine the vulnerability of this project to climate change (e.g., whether and how climate change might affect your ability to reach your objectives) you will want to assess the vulnerability of the stream habitat in the area and, perhaps, the native fish species itself. You also may need to assess the vulnerability of your various restoration approaches themselves (e.g., culvert infrastructure).

Geographic Scale

It also will be important early on to determine the appropriate spatial for your assessment. Again, this may be informed or pre-determined by an existing policy or program. For example, the GLRI is focused on specified AOCs; many project-specific assessments will start at that scale. Projects more broadly targeted to ecosystem resilience, on the other hand, will likely focus on a larger scale. Even in the former case, however, it will be important to look beyond the confines of a specific jurisdictional line. By its nature, climate change will require that we think and plan within the context of larger landscapes, even when our management needs are very local. The appropriate geographic scale must reflect both particular management jurisdictions or requirements, and the geographic requirements of the species or ecosystems you are targeting.

Temporal Scale

Another primary consideration is your timeframe. One question that restoration planners will need to ask is: Will significant climate changes occur during the life span of the project? For many restoration projects, anticipated life span – the length of time that ecological services or other benefits are expected to accrue from the project – is long enough that significant changes will almost certainly occur. A restored wetland, for instance, would be expected to remain functional as a wetland for decades; restoration should thus be carried out in a way that maximizes the chance the wetland will remain functional regardless of future changes in factors such as lake level and precipitation. Indeed, as noted below, many regions, including the Great Lakes, are already experiencing

changes consistent with climate change. Accordingly, even projects that might be considered over a shorter life span should at least recognize any of the climate conditions under which they are being developed that likely no longer reflect historical conditions.

Once you have determined your objectives/targets and geographical/temporal scales, gather the relevant data and expertise to help you assess the vulnerability of your project. For many projects, much of the information you will need may be available in scientific literature. You also may want to inquire with outside experts for their input. In addition to the citations referenced in the following tables, Appendix B of this report identifies some useful sources for more information.

B. Assess the Components of Vulnerability

Assessing Sensitivity

Assessing the sensitivity of your restoration targets/goals to climate change requires knowledge of how factors such as the life-cycle and habitat needs of species, the components and structure of habitats, and ecosystem processes are affected by climatic variables. In many cases, restoration project planners will already have at least a general sense of whether and how their targets are likely to be sensitive to general changes in these types of variables. Factors related to sensitivity to climate change will vary depending on whether your targets are species, habitats, or ecosystems (see Table A).

Table A. Elements of Climate Change Sensitivity among Species, Habitats, Ecosystems

Biological Level	Sensitivity Factor	Examples
Species	Physiological factors	Changes in temperature, moisture, CO ₂ concentrations, pH, salinity may affect a species sensitivity to climate change.
	Dependence on sensitive habitats	Species that breed in vernal pools, ephemeral wetlands, intermittent streams and species that live in low-lying coastal zones are examples of species that will be more sensitive to climate change.
	Ecological linkages	Impacts on predators, competitors, prey, forage, host plants, diseases, parasites, etc. will affect sensitivity.
	Phenological changes	Events such as leafing and flowering of plants, emergence of insects, migration of birds may be affected by climate change.
	Population growth rates	Species that can quickly recover from low population numbers are likely to be less sensitive to climate change/disruptions.
	Degree of Specialization	Generalist species, such as those that use multiple habitats, have multiple prey, etc. are likely to be less sensitive than specialists.
	Reproductive strategy	Species with long generation times and fewer offspring are likely to be more sensitive to climate change
	Interactions with other stressors	Some factors may exacerbate sensitivity (e.g., exposure to pollutants may increase sensitivity to temperature changes).
Habitats	Sensitivity of component species	Sensitivity of dominant species, ecosystem engineers, keystone species, etc. will influence sensitivity of habitat type
	Community structure	The level of diversity and redundancy of component species and functional groups may affect sensitivity to climate change.
	Degree of intactness	Degraded habitats may have insufficient species diversity or population sizes to resist or recover from flood or drought.
Ecosystems	Sensitivity of component species	As with habitats, sensitivities of dominant, keystone, and indicator species are likely to have large influences on sensitivity of the ecosystem.
	Sensitivity of ecosystem processes	Many ecosystem processes, such as decomposition, nutrient transport, sedimentation, streamflow, etc. are sensitive to changes in temperature and precipitation.

The recognition that many freshwater and marine fish species have specific temperature tolerances is a useful example of species' sensitivity to climatic variables. In the Great Lakes, for instance, common species are classified as either warm-, cool-, or cold-water fish, depending on their optimal temperature ranges (see Figure A.2). Changes in temperatures can contribute to changes in fish distribution as well as fish productivity. Another example of sensitivity to climate change is the extent and composition of wetland vegetation types and associated wildlife species, which may be sensitive to changes in average water depths. For example, many waterbird species have certain preferred water depths for foraging.¹³³ Accordingly, these species may be considered vulnerable to changes in average water depths due to altered temperature or precipitation patterns and relevant changes in wetland habitat.

Assessing Exposure

The primary ways to assess exposure to climate change and related impacts is through a solid understanding of current regional climatology and the use of climate and ecological models. However, in all likelihood, those involved in the design and on-the-ground implementation of restoration projects will not be conducting sophisticated and complex climate modeling themselves but will instead rely on existing scenarios and make use of available downscaled projections. In some cases, project managers may rely on application of ecological models, although even those models may be supplanted or bolstered by existing studies in the scientific literature or by means other than modeling, such as consulting experts.

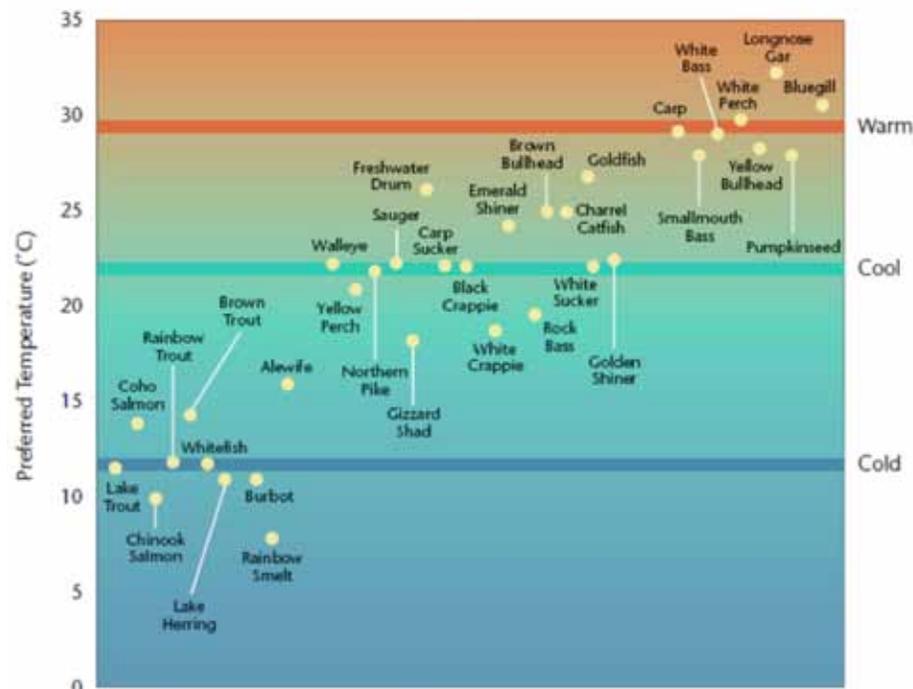


Figure A.2. Common Fish Species of the Great Lakes Region, Grouped into Thermal Guilds.¹³⁴ Source: Based on information provided by Brain Shuter. Credit: Amanda Walt/DG Communications

Climate-Related Changes

Here, we provide a few examples of the key climate-related changes that have been observed and projected for the Great Lakes region. In addition to the studies referenced in the following tables, Appendix B identifies several useful resources for identifying both observed and projected climate change impacts in the region. Note that for many of the variables, both past and future exposure may be strongly influenced by land use change.

Observed Trends

One of the most important things to consider is the fact that climate change is not just about what will happen decades from now. The Great Lakes region is already experiencing significant changes consistent with climate change, as highlighted in Table B.¹³⁵ Many of these trends are relevant for consideration in restoration project design and implementation in the short term, even as projections remain unavailable or uncertain.

Projected Climate Change

While many planners, designers, and others commonly integrate future conditions, including uncertainty, into their thinking, doing so is novel for many, and climatic uncertainty has been less commonly addressed than political or social uncertainty. Table 14 provides a general (i.e., not comprehensive) list of projections that will be important for restoration project design. These are not

Table B. 20th Century Climate Trends for the Great Lakes Region

Temperature	Average annual temperatures have increased across the region since the mid-1950s, especially in winter months. ¹³⁶
	The date of the last spring freeze occurs about one week earlier and the length of the growing season is about one week longer than it was in the early 20 th century. ¹³⁷
Precipitation	Increases in fall precipitation since the mid-1900s is resulting in increased annual mean and low flow of streams, without any changes in annual high flow. ¹³⁸
	There has been an increase in average annual lake effect snow during the 20 th century, which may be a result of warmer Great Lakes surface waters and decreased ice cover. ¹³⁹
	There has been a doubling in the frequencies of heavy rain events (defined as occurring on average once per year during the past century) and an increase in the number of individual rainy days, short-duration (1-7 days) heavy rain events, and week-long heavy rain events. ^{140,141}
Hydrology	Since 1960, average spring snow cover has decreased, followed by earlier dates for spring melt, and peak stream flow and lake levels. ¹⁴²
	Ice and snow cover and duration have decreased across the Great Lakes, more rapid than any changes that have occurred over at least the last 250 years (1975-2004). ¹⁴³
	There has been a significant shift in the timing and range of the seasonal hydrological cycle for Lake Michigan-Huron over the past century, with greatest changes occurring during winter and spring as snowmelt and runoff are shifting earlier in the year. ^{144, 145}
	The formation of ice on inland lakes is occurring later in the year than it did a century ago, and there is a shorter overall duration of winter lake ice, with some years being entirely ice-free. ¹⁴⁶
	There has been a significant decrease in Lake Michigan annual maximum ice concentration, from its long-term (1963-2001) average of 33% to the most recent 4-year average (1998-2001) of 23%, setting a new record low. ¹⁴⁷
	Great Lakes near-shore water temperatures (measured at Sault Ste. Marie and Put-In-Bay) have been rising about 0.1 degree C per decade, accompanied by an increase in the duration of summer stratification of more than two weeks, since the early 1900s. ¹⁴⁸
	Lake Superior summer (July-September) surface water temperatures have increased approximately 2.5 degrees C over the interval 1979-2006, significantly in excess of regional atmospheric warming. The discrepancy is caused by declining winter ice cover, which is causing the onset of the positively stratified season to occur earlier and increasing the period over which the lake warms during summer months. ¹⁴⁹
Ecological Impacts	Plants are leafing out and blooming up to two weeks earlier in spring than they did in the early- to mid-1900s. ¹⁵⁰

predictions of what will be – no one has a crystal ball. Rather, they are projections based on studies using a range of models, approaches, and assumptions, and they represent a range of levels of uncertainty. For example, some projections – such as for temperatures – show considerable agreement across multiple studies, while others – such as for Great Lakes water levels – do not. These discrepancies can be due to a number of factors, such as which emissions scenarios and/or models are used. One way to interpret these discrepancies is from the perspective of the level of confidence you might place on any given set of projections.

Before highlighting some of the recent projections for climate change in the Great Lakes region, we address three key questions project developers should ask about climate scenarios: how much detail they really need, at what scale they need it, and, if they need detailed scenarios, what set of scenarios to use.

- **Level of Detail.** In general, the level of detail you need in projections of future climate is roughly the level of detail about current climatic conditions you typically use in developing project plans. If you use hard numbers for maximum expected rainfall per 24-hour period, first frost date, or growing degree-days, it may be useful to you to get numerical projections for the variables you use. For many planning decisions, however, it may not be essential to know the specific climate projections. In many cases, knowing the general direction and range of likely changes (e.g., warmer water temperatures, higher spring streamflows, less winter ice cover) will be sufficient to make some general planning decisions. Often, people become too invested in the details of the particular

scenarios they are using, or become distracted from their overall goals in favor of debating the certainty or plausibility of particular scenarios. People may also invest significant time and resources on issues related to getting downscaled climate projections only to find that they have not even begun to address other critical issues such as how species may respond to changing conditions.

- **Downscaled Climate Projections.**

One of the primary concerns that resource managers frequently express in terms of incorporating climate change into their respective activities is the perceived lack of sufficiently “downscaled” studies in terms of both localized projections of climate change and the potential responses of species and ecosystems to those changes.¹⁵¹ There have been considerable advances in model development in recent years, including methods to synthesize results from global climate models (GCMs) to a geographic scale considered to be better suited for resource management decisions. Many of the resources identified in Appendix B include studies using downscaled approaches.

Despite their level of specificity and detail, downscaled models are not necessarily more “accurate” than models focused at a larger scale. Rather, the degree of uncertainty in these models may be equal to or greater than in broader-scale models, and no model will ever predict the future with complete certainty. In some cases, broader regional projections may suffice in informing restoration decisions. In others, even downscaled model results might not be sufficient, such as in areas where there is considerable diversity in geographical features or other factors that might contribute to “micro-climates” (e.g., north-

facing, highly-vegetated slopes). In these cases, supplementing information from models with on-the-ground knowledge and/or monitoring may be particularly important. In all cases, managers should avoid falling into a “predict and provide” mental framework based on the output of one or a few model projections. Nevertheless, it will be important for restoration project planners to work with scientific experts in the region to assist in identifying and/or developing downscaled projections relevant for project design at a localized level. The newly-formed Landscape Conservation Cooperatives (LCCs) (including the Upper Midwest/Great Lakes LCC) and Climate Science Centers (including the Northeast Climate Science Center) will be important resources for scientific information on climate change (see Appendix B for contact information).

- **Considerations for Choosing Climate Change Scenarios.** Which scenarios are most appropriate depends on factors such as the length of your planning horizon, the sensitivity of key species or processes, the level of confidence in the projections, and the level of acceptable risk.

The suite of climate change scenarios on which most projections are based come from a set of scenarios developed by the Intergovernmental Panel on Climate Change (IPCC) in its *Special Report on Emissions Scenarios* (SRES) in 2000.¹⁵² The scenarios span a range of possibilities for future greenhouse gas emissions. The low-emissions scenarios (e.g., B1) are no longer plausible, given current and likely near-term future emissions. Current emissions trajectories are higher than those in the IPCC’s highest emissions scenario, A1FI, but strong emissions reduction initiatives would allow us to track moderate emissions

scenarios such as the IPCC’s A2 and A1B scenarios. These are the most commonly used scenarios, and have the richest data available for modeling and projections.

Ideally, restoration investments will endure for many decades to come – from that perspective, knowing what the climate might look like 50-100 years from now is important. However, some changes are likely to happen gradually over time, and the most significant impacts may not be realized within the realistic lifespan of project-related infrastructure. In such cases, it might be sufficient to plan for projected changes in the relative near term, say 20-30 years, with the understanding that modifications in project design and/or implementation might be necessary down the road. Also, typically, near term projections of climate change scenarios have a higher degree of certainty than those that look farther out. This is true for many reasons, not least because it is difficult to anticipate how greenhouse gas emissions might change in the future, whereas the climate change we experience over the next few decades will be heavily influenced by past emissions. On the other hand, not all climate change impacts will happen gradually – in fact, it is likely that we will experience extreme events and even surprises along the way. Accordingly, designing projects to be robust to climatic variability and disturbances from the start will be important in some cases.

Table C provides a summary of some of the general and downscaled climate change projections that have been developed for the Great Lakes region. These projections should not be considered recommended scenarios for your assessment. Rather, they represent a range of information based on the best available science to date.¹⁵³

Table C. 21st Century Climate Change Projections for the Great Lakes Region

Temperature	Based on statistical downscaling methods applied to a relatively coarse-scale atmosphere-ocean GCM (AOGCM), annual temperatures in the U.S. Great Lakes region are projected to increase 1.4 +/- 0.6 degrees C over the near term (2010-2039), by 2.0 +/- 0.7 C under lower and 3 +/- 1 C under higher emissions by midcentury (2040-2069) and by 3 +/- 1 C under lower and 5.0 +/- 1.2 C under higher emissions by end-of-century (2070-2099), relative to the historical reference period 1961-1990. Simulations also suggest seasonal and geographical differences in warming, consistent with recent trends. ¹⁵⁴
Precipitation	The region is projected to see Increases in winter and spring precipitation of up to 20% under lower and 30% under higher emissions are projected by end-of-century, while projections for summer and fall remain inconsistent. ¹⁵⁵
	Average annual precipitation is projected to increase across the majority of Great Lakes basins by 2050, ranging from a 4.1% increase (+/- 4.9% uncertainty) for Lake Superior, 12.5% (+/- 4.5%) for Lake Michigan, 10.9% (+/- 4.8%) for Lake Huron, 21.8% (+/- 8%) for Lake Erie, and 19% (+/- 5%) for Lake Ontario. ¹⁵⁶ Precipitation may decrease along the Southwestern edge of the Great Lakes region, however. ¹⁵⁷
Hydrology	Downscaled regional projections of precipitation and air temperature changes in the four states surrounding Lake Michigan based on IPCC emissions scenarios suggest that impacts on streamflow on early- (water years 2010-2039) and mid-century (water years 2040-2069) streamflow was highly variable; however, by the late-century period (water years 2070-2099) annual streamflow was found to have increased in all rivers studied. ¹⁵⁸
	Summer and fall low flows in some river basins are projected to become even lower due to higher air temperatures, greater evapotranspiration losses, a longer evapotranspiration/evaporation season and reductions in groundwater base flow. ^{159, 160}
	As air temperatures increase, Great Lakes surface water temperatures are projected to increase, along with increases in the duration of summer stratification. ¹⁶¹
	Average lake temperatures are projected to increase 1.5 degrees C above the base case (1960-2000) by 2050 in Lake Superior, 0.2 degrees C in Lake Michigan, 0.3 degrees C in Lake Huron, 0.8 degrees C in Lake Erie, and 0.37 degrees C in Lake Ontario. ¹⁶²
Great Lake Water Levels	Studies using scenarios from two of the primary GCMs project significant declines in mean Great Lake water levels by the 2030s due to a combination of increased evaporation and decreased runoff, including a 22-centimeter decline under the baseline level for Lake Superior; a 72-centimeter decline for Michigan-Huron; a 60-centimeter decline for Erie; and a 35-centimeter decline for Ontario. ^{163, 164}
	Competing effects of shifting precipitation and warmer temperatures suggest little change in Great Lakes levels until the mid- to late-21 st century, when significant net decreases are expected under higher emissions. ¹⁶⁵
	According to a 2009 study that applied the output of 565 model runs from 23 different GCMs to a lake-level model developed by the Great Lakes Environmental Research Laboratory, the impact of climate change on Great Lakes water levels will vary based on which emissions scenario is used. For Lake Michigan-Huron, the median changes in lake levels at 2080-2094 were -0.25, -0.28, and -0.41 meters for low, medium, and high emission scenarios, respectively. Similar trends were projected for Lakes Erie and Ontario, while Lake Superior showed a relatively smaller response. Under some scenarios, lake levels rose by up to 1.5 meters. ¹⁶⁶

Ecological Responses to Climate Change

In addition to projecting climate changes themselves, models can provide an important means for projecting possible responses of species, habitats, and ecosystems to those changes. Ecological response models are a critical part of the overall vulnerability assessment

process, and there are numerous types of models available, ranging from basic conceptual models that provide qualitative descriptions and diagrams of key attributes and processes related to species or systems of concern, to detailed ecological models that can evaluate how climate change variables affect fundamental ecological processes.

Table D. Summary of Climate Change Impacts on Great Lakes Coastal Wetland Hydrogeomorphic Site Types¹⁶⁷

Wetland Site Type	Major Characteristics	Main Impacts of Climate Change
Lacustrine	<ul style="list-style-type: none"> Open to and most affected by Great Lakes, including water level fluctuations, nearshore currents, ice scour, and seiches (standing waves). Wetlands in open and protected bays. Varying degrees of organic sediment and vegetation development. Bathymetry, gentle to steep slope, dependent on degree of protection from lake effects and geology (ice scour and seiches). 	<ul style="list-style-type: none"> Potential for more exposure to extreme winter storms and less ice protection. Aquatic, submergent and emergent vegetation may migrate lakeward with lower levels if suitable sediment, slope, and seed banks exist. Drier vegetation communities (sedges, grasses, and shrubs) expand in current wetland. Warmer temperatures may result in vegetation community shifting over decades and centuries, starting with changes in species composition and dominance, if seed access (e.g., corridor, birds). Cumulative stresses may encourage spread of invasive species. Loss and contamination from increased demands for dredging. Mud flats exposed. Less interspersed.
Riverine	<ul style="list-style-type: none"> Occur near the mouth of tributaries to and connecting channels of the Great Lakes. Water quality, inflow and sediment loading are strongly influenced by runoff from the watershed but also affected by the lake. Often protected from waves. Types include: open to the lake, along connecting channels, behind barrier bars, and in delta. Steep river bank and river channel, with flat flood plain. 	<ul style="list-style-type: none"> More variable river flooding regimes affect wetland which can lessen influence of lake levels. More sedimentation from more extreme precipitation events causing more erosion upstream; vegetation covered with sediments and fish and wildlife habitat adversely affected. Lower flows may increase pollutant concentrations. Warmer water temperatures decrease dissolved oxygen. May be able to migrate toward river-mouth as levels decline but dependent on sediment, slope, and seed bank. Warmer temperatures may result in vegetation community shift over decades and centuries, starting with changes in species composition and dominance. Cumulative stresses may encourage spread of invasive species.

(table continued on page 52)

However, as with climate change, it is unlikely that on-the-ground restoration planners and managers will actually conduct extensive modeling as part of the planning process. More often, it will be important to rely on existing information from the scientific literature, much of

which is based on the more complicated modeling work (see, for example, Table D). Several additional sources of information are listed in Appendix B under Climate Change Impacts. It is important to recognize that many of the impact studies incorporate two of the three components

(table continued from page 51)

<p>Barrier-Enclosed</p>	<ul style="list-style-type: none"> • Occur behind a barrier beach formed by coastal processes. • Gradual slope but barrier beach is an obstruction to downslope vegetation movement once a particular water level threshold has been reached. • Generally protected from waves but may be lake-connected during high water periods (or extreme storms). • Varying connectivity to lake and influence by lake water levels. • Includes barrier beach and swale complexes between relic beach ridges with decreasing lake level influence as move landward. • More prevalent in lower lakes where more coastal sediments are available. 	<ul style="list-style-type: none"> • Unable to shift lakeward with lower lake levels so gradual drying of wetland; dominated by meadow, shrub, and tree communities with associated shift in diversity, productivity, and habitat value. • Drying may increase risk of fire. • Shifting coastal processes may alter barrier or re-form a lakeward one. • Warmer temperatures may result in vegetation community shift over decades and centuries, starting with changes in species composition and dominance, if seed access (e.g., corridor, birds). • Warmer water temperatures decrease dissolved oxygen. • Cumulative stresses may encourage spread of invasive species. • Wetland area decreases.
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of vulnerability: sensitivity and exposure. Thus, they fit into the top three boxes of the framework illustrated in Figure A.1, above. As we describe below and elsewhere in this guidance, assessing the other key component – adaptive capacity – may require additional attention in the restoration planning process.

Assessing Adaptive Capacity

Determining the adaptive capacity of your restoration targets/objectives entails asking several questions, including: whether and how much those targets are already able to accommodate changes in climate (e.g., innate features such as dispersal abilities); whether and to what extent barriers exist that limit your targets' adaptive capacity (e.g., natural or physical structures that prevent habitat migration,

or institutional restrictions such as inability to manage impacts beyond existing jurisdictional boundaries); and are there additional stressors that limit the adaptive capacity of your targets (e.g., the presence of an opportunistic invasive species that outcompetes restored vegetation).¹⁶⁸ Table E highlights elements of adaptive capacity for restoration targets.

Many of resources available on species/ ecosystem sensitivity also will be useful for determining innate features that might contribute to or limit adaptive capacity. Similarly, for regions such as the Great Lakes in which existing stressors have been extensively analyzed and documented, there will likely be a considerable body of information available to help determine how they might come into play with climate change as an added stressor.

Table E. Elements of Adaptive Capacity among Species, Habitats, and Ecosystems

Biological Level	Adaptive Capacity Factor	Examples
Species	Plasticity	The ability for a species to modify its physiology or behavior to synchronize with changing conditions or coexist with different competitors, predators, etc.
	Dispersal abilities	Some species may be able to disperse over long distances (e.g., seeds may be carried to new areas by birds). Other species, such as those that have evolved in patchy or rare habitats, may have lower dispersal ability.
	Evolutionary potential	Traits such as generation time, genetic diversity, and population size can affect the ability of species to adapt evolutionarily to climate change. For example, populations with high genetic diversity for traits related to climate tolerance are more likely to contain individuals with heritable traits that reduce sensitivity.
Habitats	Permeability of landscape	More permeable landscapes with fewer barriers to dispersal and/or seasonal migration will likely result in greater adaptive capacity. Relative permeability of a landscape may depend on natural and anthropogenic factors
Ecosystems	Redundancy and response diversity within functional groups	In ecological communities, functional groups can include primary producers, herbivores, carnivores, decomposers, etc. In systems where each functional group is represented by multiple species and the response to environmental change varies significantly among species in the group, the system's resilience to climate change is likely to be higher.

C. Summarize Vulnerability

Once you have an understanding of the how each of the components of vulnerability applies to your project goals/approaches, the next step in the assessment process is to summarize overall vulnerability based on your findings.¹⁶⁹ Vulnerability assessments can provide two essential types of information needed for restoration planning: 1) identifying which species or systems are likely to be most strongly affected by projected changes, and 2) understanding why they are likely to be vulnerable. This information will help you set priorities as well as provide a basis for developing appropriate management responses. How to characterize the results of your vulnerability assessment may range from a general determination of the relative degree of vulnerability (e.g., low,

medium, high), to detailed narratives that delve into specific information regarding your assumptions, results, etc. The more descriptive you are in your assessment results, the more useful the information is likely to be in helping you determine possible management approaches. Tables 1-9 in Section IV of this guidance illustrate how one might characterize vulnerability for several hypothetical Great Lakes restoration projects.

More detailed information about climate change vulnerability assessments, along with a number of case studies, can be found in Glick, P., B.A. Stein, and N.A. Edelson, editors. 2011. *Scanning the Conservation Horizon: A Guide to Climate Change Vulnerability Assessment*. National Wildlife Federation, Washington, D.C.: www.nwf.org/vulnerabilityguide.



Anne de Haas Photography

Box A.1. Addressing Uncertainty in Vulnerability Assessments

Assessing the vulnerability of species, habitats, or ecosystems to most stressors, and certainly to climate change, is complex, and there are different levels of certainty and confidence in each piece of scientific information and expert knowledge that are integrated together to produce a vulnerability assessment. Uncertainty is a reality: No one knows exactly how climate may change or how ecological or human systems may respond to change, in any particular location. Nevertheless, management decisions can proceed in the face of uncertainty. A useful way to characterize uncertainty in the assessment process is the level of confidence in a given input or outcome. In some instances we will have a high level of confidence in some or all of the parts determining climate change vulnerability, and in other cases we may be less certain in one or more of the vulnerability factors.

The goal should be to use the best available information on the uncertainties involved in estimating vulnerability, while recognizing that it may be necessary to reassess vulnerability and the associated uncertainties in an iterative fashion as new information becomes available. Being transparent about the general magnitude of uncertainty and understanding the range of possibilities given the uncertainty allows managers to articulate the reasoning for making a decision.

Appendix B.

Additional Resources

Organizations and Web-Based Resources

- The Upper Midwest/Great Lakes LCC website: <http://www.fws.gov/midwest/climate/LCC/UpperMidwest>.
- The Northeast Climate Science Center website: http://www.doi.gov/whatwedo/climate/strategy/Northeast_CSC.cfm.
- Researchers at the University of Michigan have recently compiled an annotated bibliography on some useful resources, including direct links to the respective publications: http://snre.umich.edu/events/2011-03-31/assisting_great_lakes_coastal_communities_with_climate_change_adaptation_master039.¹⁷⁰
- The **Climate Adaptation Knowledge Exchange (CAKE)** website also provides an extensive, searchable selection of climate change information and resources, which is being regularly updated: <http://www.cakex.org>.
- NOAA's **Coastal Services Center** has a website dedicated to providing key resources on coastal adaptation, including relevant climate science and impacts: <http://collaborate.csc.noaa.gov/climateadaptation/default.aspx>.
- The NOAA-funded **Great Lakes Regional Integrated Sciences and Assessments (GLISA)** program conducts

research on regional and localized impacts of climate change: <http://www.graham.umich.edu/centers/galisa.php>

- **Regional Sea Grant** offices also are a good resource for climate change information: <http://www.glerl.noaa.gov/seagrant/>, as is the **Wisconsin Initiative on Climate Change Impacts**: <http://www.wicci.wisc.edu/>.

Climate Change Trends and Projections

- The following study provides useful “downscaled” climate change projections for the region: Hayhoe, K., J. VanDorn, T. Croley II, N. Schlegal, and D. Wuebbles. 2010. Regional climate change projections for Chicago and the U.S. Great Lakes. *Journal of Great Lakes Research* 36: 7-21. <http://www.bioone.org/doi/abs/10.1016/j.jglr.2010.03.012>.
- In 2000, the U.S. Global Change Research Program undertook a comprehensive national assessment of climate change impacts in the United States, with summaries focused on the Great Lakes and other regions. While there have been more recent modeling efforts, these assessments provide a useful foundation: Sousounis, P.J. and J.M. Bisanz, editors. 2000. *Preparing for a Changing Climate: The Potential Consequences of Climate Variability and Change*, Great Lakes. U.S. Global Change Research Program,

Washington, D.C. <http://www.gcrio.org/NationalAssessment/greatlakes/greatlakes.pdf>.

- Mortsch and Quinn (1996) compiled a range of possible climate change scenarios for use in Great Lakes Basin ecosystem studies, based on results from running several general circulation models under a doubling of atmospheric CO₂ from present (1990s) levels (which is plausible by mid-century). They project both direct and indirect impacts on the Great Lakes ecosystem, including significant spatial variability on a tributary river-basin scale. http://www.aslo.org/lo/toc/vol_41/issue_5/0903.pdf.

Climate Change Impact Studies

- The Union of Concerned Scientists report, *Confronting Climate Change in the Great Lakes Region* (2003) and accompanying website provide a comprehensive summary of the state of the science of climate change and its impacts in the region: <http://www.ucsusa.org/greatlakes>.
- The National Park Service has developed a useful summary guide, *Understanding the Science of Climate Change: Talking Points – Impacts to the Great Lakes* (2010): <http://www.nature.nps.gov/climatechange/docs/GreatLakesTP.pdf>.
- Researchers at Environment Canada/University of Waterloo and the U.S. Environmental Protection Agency compiled an excellent overview report for the Great Lakes Water Quality Board of the International Joint Commission, *Climate*

Change and Water Quality in the Great Lakes Region: Risks, Opportunities, and Responses (2003): http://www.ijc.org/rel/pdf/climate_change_2003_part3.pdf.

- Environment Canada also has published a detailed vulnerability assessment for coastal wetland communities, with a focus on lake level changes: Mortsch, L., J. Ingram, A. Hebb, and S. Doka. 2003. Great Lakes Coastal Wetland Communities: Vulnerabilities to Climate Change and Response to Adaptation Options. http://adaptation.nrcan.gc.ca/projdb/pdf/86b_e.pdf.

Climate Change Adaptation

- The U.S. Climate Change Science Program (CCSP) has developed a Preliminary Review of Adaptation Options for Climate-sensitive Ecosystems and Resources (2008): <http://downloads.climatescience.gov/sap/sap4-4/sap4-4-final-report-all.pdf>.
- The Association of Fish and Wildlife Agencies has developed *Voluntary Guidance for States to Incorporate Climate Change into State Wildlife Action Plans and Other Management Plans* (2009): http://www.fws.gov/southwest/Climatechange/docs/afwaClimatechangeGuidanceDocument_UpdatedSept3_FINAL.pdf.
- In addition, numerous articles on the subject are available in the scientific literature.^{171, 172, 173}

Endnotes

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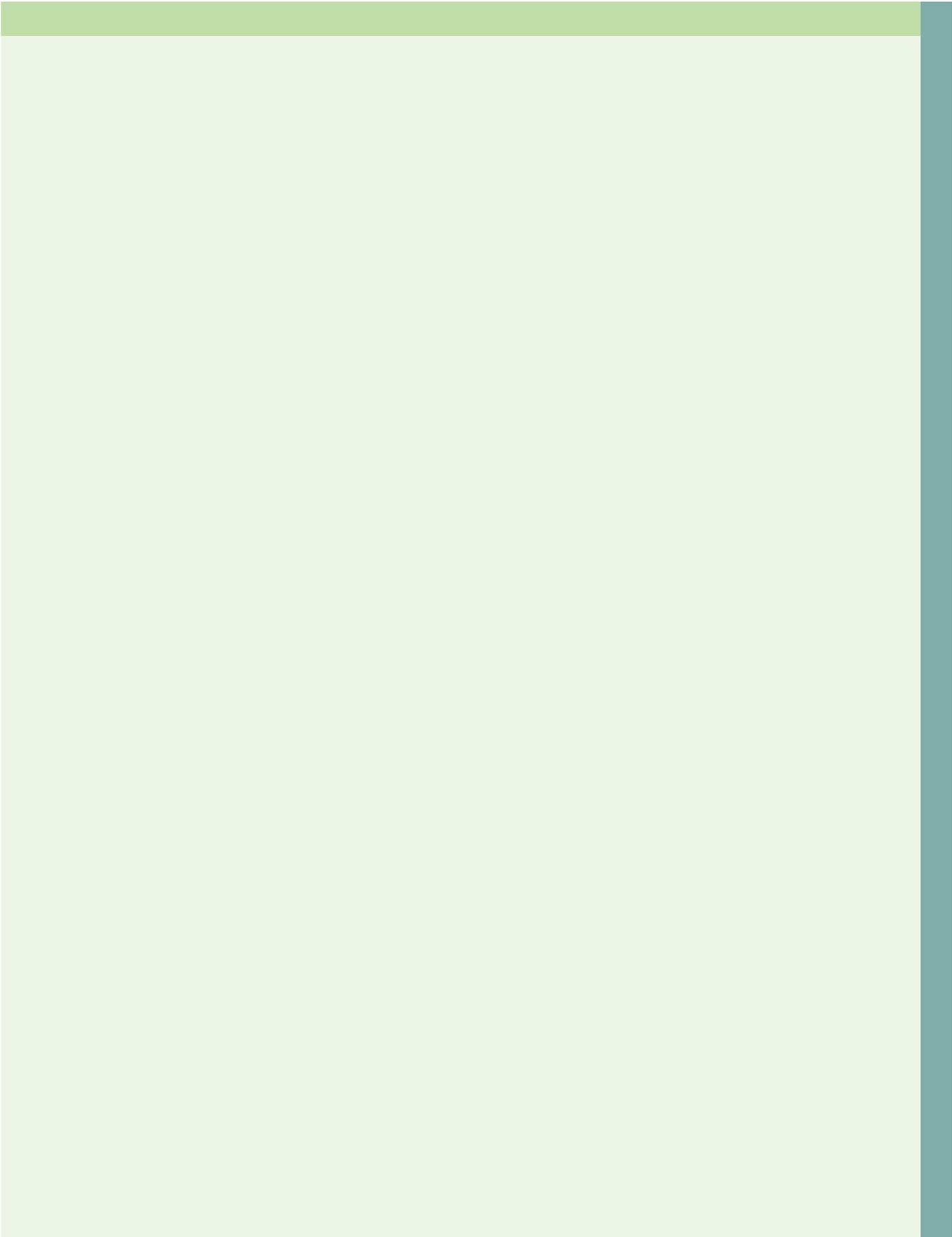
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